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MARINE BOILERS

MARINE BOILERS

THEIR CONSTRUCTION AND WORKING DEALING MORE ESPECIALLY WITH TUBULOUS BOILERS

BASED ON THE WORK BY

L. E. BERTIN

LATE CHIEF CONSTRUCTOR OF THE FRENCH NAVY

TRANSLATED AND EDITED BY

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SECRETARY OF THE ENGINEERING STANDARDS COMMITTEE, M.INST.C.E., M.INST.M.E., M.INST. NAVAL ARCHITECTS, ETC., ETC.

WITH A NEW CHAPTER ON "LIQUID FUEL," BY

ENGINEER-LIEUTENANT H. C. ANSTEY, R.N.

ASSOC.M.INST.C.E., M.INST.M.E.

AND A PREFACE BY SIR WILLIAM WHITE, K.C.B., F.R.S.

SECOND EDITION REVISED AND ENLARGED

WITH UPWARDS OF 350 ILLUSTRATIONS

NEW YORK

D. VAN NOSTRAND COMPANY

1906

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Printed in Great Britain

EDITOR'S PREFACE TO SECOND EDITION.

SINCE the appearance of the First Edition, marine practice has made many strides, but progress has been rather in the direction of concentrating practice, along well acknowledged lines, than by the introduction of any noticeable departure in the design of boilers. Considerable development has taken place in the application of steam turbines to marine propulsion, but it has not called for any change in the types of boilers already in use.

The most notable addition to the present volume is the chapter on "Liquid Fuel" which has been specially written for this edition by Engineer-Lieutenant H. C. ANSTEY, R.N., and gives the latest British practice and the most recent developments, in what may, in the future, see considerable advances, and exercise no inconsiderable influence on naval design and tactics.

Since the publication of the First Edition the Boiler Commission have issued their final Report which together with the first Report I have added as Appendices.

The recent visit of the French Northern Squadron to this country will, I feel sure, enhance the interest attaching to the present volume, as particulars of several of the vessels that visited Portsmouth will be found therein.

I beg to tender my thanks to the various firms who have again so kindly placed particulars of their recent practice at my disposal, and particularly to Mr H. C. ANSTEY

and Mr CHARLES DRESSER for their assistance in the revision of the First Edition, as also to Mr JOHN MURRAY for his care and patience in carrying the present Second Edition through the press.

LESLIE S. ROBERTSON.

28 VICTORIA STREET,
WESTMINSTER, S.W., *October* 1905.

PREFACE TO FIRST EDITION.

By Sir WILLIAM H. WHITE, K.C.B., F.R.S.,

Late Director of Naval Construction, and Assistant-Controller of the Royal Navy.

At the request of both the Author and the Translator I have undertaken to introduce to English readers this version of a standard French work on "Marine Boilers." It is a pleasant task, since the book is certain to receive a welcome from all who are interested in the production and use of steam-power.

Although M. Bertin is so well known, not merely in France but in all maritime countries, I may be permitted to indicate briefly what his claims are to deal with this important subject. He is one of the most eminent members of that distinguished body, the Génie Maritime. His career has embraced long service in the French dockyards, at sea, and in the Ministry of Marine. He has been engaged for some years as principal technical adviser to the Japanese Ministry of Marine, under special permission of the French Government. Since his return from Japan he has occupied the important posts of Principal of the

Ecole d'application du Génie Maritime, Directeur du Matériel, and Chef du Service Technique at the Ministry of Marine. The last-named office he now occupies; and, under existing regulations, he is responsible to the Minister of Marine for the practicability and technical accuracy of the designs for all new French ships. As a matter of fact, M. Bertin is the responsible designer of the latest and swiftest cruisers now building in France. Consequently, no one is better placed for speaking authoritatively and with complete information respecting the most recent French practice in marine engineering and boiler construction.

The book originated in courses of lectures given to the students at the Ecole d'application du Génie Maritime. It is well known that the French system of education for these students embraces training in both naval architecture and marine engineering. With us, after a short preliminary training in common, the courses of study for the two branches diverge and become specialised. It is still true, however, that every competent naval architect must have an intimate acquaintance with marine engineering, and that every fully-equipped marine engineer must be conversant with the principles of ship construction. M. Bertin has produced a book, which is of interest and value to both marine engineers and naval architects. The former will find ample information respecting the

history, development, and details of construction of various types of boilers. The naval architect will find, in addition, particulars such as are essential to the preparation of ship designs.

As compared with English text-books, perhaps the chief interest of this work will be found in the sections dealing with tubulous boilers. In the use of such boilers for marine purposes French engineers have shown remarkable courage and enterprise. The mercantile marine offers many examples of this fact; but it is in the French War Fleet that most has been done. In fact, the tubulous boiler now reigns supreme from the torpedo-boats up to the largest cruisers and battleships. A change such as this, carried through in a comparatively short time, has necessarily involved much of an experimental nature. M. Bertin deals with the subject frankly and exhaustively. He traces the history of each type of boiler, enumerates its advantages and its disadvantages, summarises its experience, and indicates the line of future progress.

All English naval architects and marine engineers are happy to acknowledge the lead which their French colleagues have taken in this matter, and the benefit which they have obtained from French experiment and experience with tubulous boilers. This book presents the best summary yet available, from a French source, of what that experience has been.

It is hardly necessary to add that in its arrangement

style, and terseness, the book is a worthy specimen of French method. In its English dress much information has been added of the latest French practice.

The work of translation has been admirably performed by Mr Leslie Robertson, whose thorough acquaintance with engineering in general, and with tubulous boiler construction in particular, make him specially qualified for the work he has undertaken.

W. H. WHITE.

October, 1898.

AUTHOR'S PREFACE TO FIRST EDITION.

WHEN the task of lecturing on "Boiler Construction" to the future engineers of the French Navy at the Ecole du Génie Maritime, where the preliminary education is purely scientific, fell to my lot, I had had considerable experience in actual construction in many branches though none in lecturing. I was much more interested in the theory of ships and their construction than in the thorough study of the propelling machinery.

My treatise on "Marine Boilers" was undertaken somewhat unexpectedly, and was prepared for a very special audience. I was led to write it chiefly because I could not find in any of the many excellent existing text-books an account of the evolution that was then going on in boiler construction. I hope this may secure for me the indulgence of English specialists, and particularly of those from whom I have frequently had occasion to borrow information.

I took a deep interest in my task when once it was begun. I had always kept abreast of the boiler question, and had the pleasure of knowing intimately M. Sochet, M. du Temple, and M. Joessel, all of whom are now dead. My official duties have made me familiar with the efforts of M. Belleville, who worked with great perseverance for a long time before they were crowned with success. The fact that I was not an inventor myself placed me in a favourable position to form an impartial judgment on the various systems now in operation.

One all important condition was, however, lacking to me,

viz., the time necessary for sustained and continuous work. I only lectured on the subject of Marine Boilers for one year, and the present work, which was published at the instigation of friends, would have been more complete if it had undergone a complete revision in a second course of lectures.

The present English edition, however, will not suffer from the precipitation that attended the publication of the original French text. The necessary work of revision has been carried through by Mr Leslie S. Robertson with great ability, and with a carefulness which it was impossible for me to exercise; there is not a figure which has not been checked, nor a calculation which has not been verified. Mr Robertson has been an invaluable collaborator. He has spent on the English translation probably more time and trouble than I devoted to the original French composition.

I offer my most cordial thanks to my learned friend, Sir William White, who has been kind enough to introduce my work to the British public. He knows that I entertain, in the highest degree, for all his works, the esteem which he has shown for mine, and he may perhaps suspect that, if I were of a jealous disposition, he would be the man of whom I should be most envious.

L. BERTIN.

PARIS, *October* 1898.

EDITOR'S PREFACE TO FIRST EDITION.

M. BERTIN, Director of Naval Construction and Chef du Service Technique in the French Navy, is well known in this country as a prominent Member of the Institution of Naval Architects, to whose Transactions he has added many valuable contributions. An English edition of his recent work on "Marine Boilers" is sure to meet with a favourable reception by all those interested in marine, and especially tubulous boilers.

The information and opinions published in the present work must carry additional weight from the fact that the Author, by virtue of his high official position, has the fullest and most recent information at his disposal. And further, the part played by the French as pioneers in the introduction of the tubulous boiler on a practical scale for naval purposes, lends particular interest to the chapters on the introduction and development of this class of boiler.

Much attention has been directed to the important question of coal consumption by the French, and the results of the trials contained in the following pages will be read with interest in view of the attention at this present moment being directed to this subject in our own Navy.

The French edition was the outcome of M. Bertin's lectures to his students at the Ecole d'application du Génie Maritime, but it has been revised and added to so as to bring the subject-matter up to date. The particulars and the tables of weights of the Jeanne d'Arc and Château-Renault, now under construction, are particularly valuable on account

of the size and importance of the installation. It also indicates an important departure from what has been up to this present time the usual practice of fitting vessels of this size with large tube boilers, such as the Belleville boiler.

In the preparation of the English edition I have adhered to the original text as far as possible, and have, after careful consideration, decided to maintain the numbers of the figures and paragraphs identical with those of the French edition, in order to facilitate reference. In the English edition, where the ground has already been covered by other text-books, some of the original French illustrations have been omitted and the subject-matter in places compressed, while in other places of special interest it has been extended, added to, and brought up to date. The value of the work has also been further enhanced by the addition to the English edition of a very complete index, which should materially add to the value of the work for purposes of reference.

The conversion of the French figures into their corresponding British units has entailed a very large amount of work, but it has enabled me to eliminate many of the little inaccuracies occurring in the original French edition, which were no doubt due to the heavy calls upon M. Bertin's time when preparing his work for the press.

The term *Chaudière à tubes directs* has throughout been rendered *direct tube boiler* or *Admiralty type boiler* in contradistinction to *Chaudière à retour de flammes* or *return tube boiler.*

It must be borne in mind that the opinions and facts advanced are those given by the Author, and that they refer in nearly all cases to French practice, which materially differs from our own.

I beg to tender my thanks to the various firms who have placed valuable information at my disposal, to Mr Frankish of Messrs John I. Thornycroft & Co., for his assistance, and especially to my assistant, Mr Charles Dresser, for the great

care and attention he has given to the preparation of the present edition.

I regret that the many calls upon my time have delayed the earlier appearance of this book; the delay has, however, had one advantage, namely, that of enabling me to include some of the most recent results which do not appear in the original French edition.

In conclusion, I beg to tender my best thanks to Sir William White, K.C.B., for the preface that he has been good enough to write for the English edition of his friend M. Bertin's work on "Marine Boilers."

LESLIE S. ROBERTSON.

WESTMINSTER, *October* 1898.

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MARINE BOILERS.

PART I.

CHAPTER I.

THE PRINCIPAL LAWS UNDERLYING STEAM NAVIGATION.

Notation Employed.

A. Weight of coal carried, in tons.

B^2. Immersed midship section in square feet.

C. Coal consumption per horse-power-hour in lbs.

D. Radius of action, in knots, without deducting, from the total amount carried, the coal used for the auxiliary engines.

D′. Radius of action, in knots, deducting coal required for auxiliaries.

F. Indicated horse-power exerted on the pistons.

F_1. Brake horse-power.

I. Coefficient $\frac{M^3}{CV^2}$ for multiplying the coefficient N in order to obtain the radius of action D.

M. and M_1. Coefficients of performance taken from the formulæ

$$\begin{cases} V = M\sqrt[3]{\dfrac{F}{B^2}} \\ V = M_1\sqrt[3]{\dfrac{F}{P^{\frac{2}{3}}}} \end{cases}$$

N. Coefficient of radius of action, neglecting consumption of auxiliary machinery.

N'. Coefficient of radius of action, including consumption of auxiliary machinery.

P. Displacement in tons.

Q. Total weight in tons of propelling machinery, including coal.

R. Resistance offered by the water to motion of the ship.

V. Speed of ship in knots.

λ. Ratio of corresponding dimensions of two similar ships or of those of a ship to those of a model.

c. Stroke of piston in feet.

d. Diameter of piston in inches.

n. Revolutions of engine per minute.

p. Total mean pressure of steam on the pistons, as shown by the indicator diagrams, in lbs. per square inch.

m. Weight per horse-power of engine in tons.

q. Consumption of the auxiliary machinery per twenty-four hours.

S, S_1. Constants in the "law of similarity." *

u. Mechanical efficiency of engine (ratio of brake horse-power F_1 to indicated horse-power F).

u_1. Efficiency of propeller (ratio of useful work performed by the screw to the brake horse-power F_1).

1. *Adoption of Steam for Marine Purposes.* — Steamships have entirely taken the place of the old sailing vessels in the navy; but in the mercantile marine this substitution is not quite so complete. With the quick transits and low freights now in vogue, the sailing vessel can no longer hold her own against her steam rival, except under certain conditions.

Sails, retained for a long time as an auxiliary means of propulsion, are now disappearing from all steamships, since the advent of multiple screws driven by independent engines. In the case of warships they have almost entirely disappeared.

* See "Manual of Naval Architecture," by Sir W. H. White, page 474, last line but one.

The results of the adoption of steam on board ship, looked at from a general point of view, are a great increase in speed and greater regularity of service.

§ 1. SPEED.

2. *Speed of Steamships.*—Speed in a sailing ship depends so largely upon the direction and force of the wind that it is extremely difficult to form an estimate of the probable length of a voyage based on a knowledge of the speed of the ship itself under favourable circumstances.

Forty or fifty years ago 4 knots was considered a good average speed for a sailing ship making a long voyage. The clippers specially built for the China trade, however, frequently made an average of 6 knots; but this was considered exceptionally good.

The steamship entered upon its career with the same speed as that obtained by the China clipper ships; the *Sphinx*, making 6 knots between Algiers and Toulon in 1830, marked the first step.

At present, cargo-carrying steamers have speeds of at least 10 knots, while the Transatlantic liners attain mean speeds of 23 knots under favourable circumstances. Large warships have speeds equal to the Transatlantic liners, but their engines rarely have sufficient endurance for a run of over 3,000 miles at a speed of 23 knots. Torpedo-boats, and other boats built for special purposes, with a very small radius of action, are not referred to here, reference being made solely to ships having a considerable radius of action.

The improvement in speed, which goes on from day to day, affects the merchant service as well as the navy, for this reason, that the safety of the former in time of war depends on their being faster than the latter.

Speed is a costly quality; speaking generally, it is

regulated in the merchant service by the competition between shipowners, and in the navy by the rivalry existing between the navies of different maritime powers.

3. *Coefficient of Performance—its two Forms.*—The elementary formulæ, which are used in practice to determine the speed of a ship as a function of the engine-power, are the following :—

Let F be the gross work done by the steam upon the pistons, proportional to the mean pressure on the piston $\frac{\pi}{4} d^2 p$, and to the space passed over in one minute $2\ c\ n$: the work absorbed in propelling the ship, calling u the efficiency of the engine, and u_1 the efficiency of the screw, equals :

$$u\ u_1\ \mathrm{F}.$$

On the other hand, if R is the ship's resistance, and V the speed of the ship, the total work done in overcoming the resistance to motion will be

$$\mathrm{R\ V}.$$

Equating these two expressions we get—

$$\mathrm{R\ V} = u\ u_1\ \mathrm{F}. \tag{1}$$

For any given vessel moving with a variable velocity, we may assume that the following law holds approximately :—

$$\mathrm{R} = \mathrm{K\ V}^2. \tag{2}$$

Now for boats of similar form but of different dimensions, the law of similarity shows that when V^2 is proportional to λ, R is proportional to the cube of λ; the following relations then hold good :—

$$\mathrm{V}^2 = s\ \lambda$$

$$\mathrm{R} = s_1\ \lambda^3$$

from which we obtain—

$$\frac{\mathrm{R}}{\mathrm{V}^2} = \frac{s_1}{s} \lambda^2$$

$$\mathrm{R} = \frac{s_1}{s} \lambda^2\ \mathrm{V}^2$$

The coefficient K, which is independent of V, should then be proportional to λ^2; this can be expressed thus :—

$$(3) \qquad K = k\ B^2$$

B^2 being the immersed midship section, it can also be written :—

$$(3a) \qquad K = k_1\ P^{\frac{2}{3}}$$

in terms of the displacement P. From these we get the two equations :—

$$(4) \qquad K\ B^2\ V^3 = u\ u_1\ F$$

$$(4a) \qquad k_1\ P^{\frac{2}{3}}\ V^3 = u\ u_1\ F.$$

From these we obtain the two following expressions for V :—

$$(5) \qquad V = \sqrt[3]{\frac{u\ u_1}{k}}\sqrt[3]{\frac{F}{B^2}}$$

$$(5a) \qquad V = \sqrt[3]{\frac{u\ u_1}{k_1}}\sqrt[3]{\frac{F}{P^{\frac{2}{3}}}}.$$

The gross work F is known; the speed V is measured on the trials; we therefore obtain a value for a coefficient, which may be written in two ways :—

$$M = \sqrt[3]{\frac{u\ u_1}{k}}$$

$$M_1 = \sqrt[3]{\frac{u\ u_1}{k_1}}.$$

This coefficient is called the "coefficient of performance" of the ship,* M being known as the "midship-section coefficient" and M_1 as the "displacement coefficient."

We have no means of determining the value of the factors u, u_1, k, or k_1, which we have only introduced to explain the coefficient of performance.

The values of M and M_1 vary for the same ship, because

* The values given for the coefficients of performance are the cube roots of the "Admiralty coefficients." See "Manual of Naval Architecture," by Sir W. H. White, page 566.

K in formula (2) changes with the velocity V, and u and u_1 vary with the revolutions of the engines.

On the other hand, for boats of similar form but of different dimensions, experiment proves that, for speeds proportional to $\sqrt{\lambda}$, the actual resistance, compared with that given by the law of similarity, is greater for small boats and less for large ones. Besides, no ships are exactly alike, and their speeds, V, do not in the least satisfy the conditions required by the law of similarity; so that for these reasons, in expressing the speed, V, by one or other of the formulæ,

$$V = M \sqrt[3]{\frac{F}{B^2}} \tag{6}$$

$$V = M_1 \sqrt[3]{\frac{F}{P^{\frac{2}{3}}}} \tag{6a}$$

we must look upon M and M_1 as variable and purely empirical coefficients. When designing a new boat their values can only be determined with any exactness if the results of trials, made upon a ship nearly identical in form, at similar rates of speed, and under precisely similar conditions, are known. Some experimenters say the depth of water must be the same in both cases.

The determination of the speed, as a function of the horse-power, requires, as has been seen, a knowledge of a great number of values of M and M_1, or rather of a great number of curves of M and M_1, plotted as a function of the speed. The determination of the speed of a boat that has to be built to a hitherto untried design, or is intended to attain speeds beyond those already realised, can be considerably facilitated by making experiments upon a model under the conditions imposed by the law of similarity. The interpretation, however, of the results obtained by these experiments requires the greatest care and attention.

The Table on page 7 gives values of M and M_1 for some recently-constructed ships for the French Navy. It will be noticed that these values sensibly decrease on passing

from the larger ships to the smaller, the resistance then becoming proportional to a power of λ, rather less than the square.

The experiments made on the *Forban* have led M. Normand to conclude that the coefficients M and M_1 have a minimum value at a certain speed for each ship; after reaching this they increase indefinitely. The speed to which this minimum value corresponds, and which for torpedo-boats of 123 tons' displacement is about 20 knots, would be approximately proportional to the sixth root of the displacement, that is to say, to $\sqrt{\lambda}$, if the law followed by these small boats held universally.

The formula (6*a*) leads to a curious result, if we assume M constant, and further, that the weight assigned to propelling machinery is a constant fraction of the displacement P.

	Name of Ship.	Speed in Knots. V	Horse-Power. F	Coefficients of Performance. M	Coefficients of Performance. M_1	Displacement on Trial. TONS.
Battleships	*Bouvet*	18·188	14,534	8·715	5·997	11,928
	Charles-Martel	18·128	14,633	8·535	5·965	11,658
	Brennus	17·107	13,768	8·251	5·630	10,869
	Magenta	16·21	10,566	8·517	5·812	10,755
	Charlemagne	17·23	11,348	8·689	6·028	10,728
	Cocyte	11·27	1,421	7·688	5·215	1,671
Cruisers	*Guichen*	23·54	25,249	8·145	5·862	7,702
	Dupuy-de-Lôme	19·73	13,015	8·222	5·799	6,008
	Sfax	16·75	6,968	8·215	5·679	4,470
	Isly	18·14	8,103	7·770	5·726	4,079
	Friant	18·89	9,316	7·994	5·566	3,679
	D'Estrées	20·22	8,652	7·493	5·510	2,318
	Lavoisier	21·57	7,411	8·036	6·097	2,167
	Troude	20·91	6,350	7·899	6·005	1,845
Torpedo-Boats	*Lévrier*	18·38	2,197	7·000	5·491	448·3
	Fauconneu	27·14	5,154	6·874	5·482	276·8
	Forban	31·03	4,121	6·981	5·669	126·3
	Chevalier	26·72	2,918	6·590	5·329	111·5
	Cyclône	29·06	3,587	6·996	5·703	101·9
	Torpilleur (230)	23·10	1,788	6·854	5·511	82·4

The weight of the engines is, according to the law of

similarity, proportional to the cube of the linear dimensions. The power which is given by the expression $F = 2\frac{\frac{\pi}{4}d^2\ c\ n\ p}{33,000}$ is only proportional to the square of the dimensions (d^2) when the mean piston speed $c\ n$ and the steam pressure p are alike in both cases. The power of the engines is then theoretically proportional to the two-thirds power of their weight.* Then, according to our assumption, the ratio F to $p^{\frac{2}{3}}$ is constant, and the speed V is therefore constant in accordance with formulæ (6) and (6*a*), whatever may be the size of the boat. There is, therefore, nothing contrary to first principles in the very great speeds that have been attained on small boats.

It was assumed above that the mean piston speed $c\ n$ was constant; this hypothesis does not hold for the case of complete similarity between two sets of propelling machinery, including engines and screw. The exact relation would then be $c\ n = \sqrt{s}\sqrt{\lambda}$ for the same steam pressure; but as a matter of fact, the engines of these small boats have a higher speed of revolution than the law of similarity would assign to them, and the equation $c\ n$ = constant, is more nearly true than $c\ n = \sqrt{s}\sqrt{\lambda}$.

§ 2. RADIUS OF ACTION.

4. *Calculation for Determining the Radius of Action.*—The greatest distance that a ship can steam—a property as important as the speed—depends upon the amount of coal carried and the speed at which the distance has to be covered. Let C be the consumption of coal per horse-power-hour in lbs.; then for a given power F, the consumption

* This of course is only true in engines having the same ratio of stroke to diameter, *i.e.* when c varies directly as d and therefore as cn is constant, n varies inversely as d. Otherwise when c and d are independent the weight is proportional to d^2c while the power is proportional to d^2cn, and the weight is therefore directly proportional to the power and inversely proportional to the speed of revolution.

equals F C; if V be the corresponding speed, the consumption per knot is—

$$\frac{\mathrm{F\,C}}{\mathrm{V}};$$

for a distance D, the coal burnt will be—

$$\frac{\mathrm{F\,C}}{\mathrm{V}} \times \mathrm{D},$$

which must be equal to the weight of coal carried in the bunkers A, and the following equation is obtained:—

$$(7) \qquad \mathrm{D} = \mathrm{A} \times \frac{\mathrm{V}}{\mathrm{F\,C}}.$$

Taking the ratio V to F from the equation (6*a*) in order to eliminate F we get

$$(8) \qquad \frac{\mathrm{V}}{\mathrm{F}} = \mathrm{M_1}^3 \times \frac{1}{\mathrm{P}^{\frac{2}{3}}} \times \frac{1}{\mathrm{V}^2}$$

from which equation it follows that, for a given ship, if A and C be constant, the radius of action D given by the formula

$$(9) \qquad \mathrm{D} = \frac{\mathrm{M_1}^3}{\mathrm{C}} \times \frac{1}{\mathrm{V}^2} \times \frac{\mathrm{A}}{\mathrm{P}^{\frac{2}{3}}}$$

is inversely proportional to the square of the speed.

If two exactly similar ships, but of different rates of speed, be compared, fitted with engines giving a maximum efficiency at the required speed, we shall find that A decreases more slowly than indicated by the law of the squares.

In reality, if the maximum power is decreased from F to F′ in direct proportion to the speed, and if the total weight of machinery, coal, &c., be constant, we shall have—

$$(10) \qquad \mathrm{A} + m\,\mathrm{F} = \mathrm{Q}$$

$$(10a) \qquad \mathrm{A}' + m\,\mathrm{F}' = \mathrm{Q}$$

from which we get

$$\mathrm{A}' = \mathrm{A} + m\,(\mathrm{F} - \mathrm{F}').$$

If we assume that the weight of coal A is equal to the weight of the propelling machinery m F, as is often the case, and if the speed of the second ship is half that of the first, which makes $\mathrm{F}' = \frac{\mathrm{F}}{8}$, we obtain

$$(11) \qquad \mathrm{A}' = \mathrm{A} + \mathrm{A}(1 - (\tfrac{1}{2})^3);$$

and A′ is then nearly double A. Under these conditions the radius of action when steaming at full speed, instead of being multiplied by four, is multiplied by eight. With the same speed the radius of action of the second ship is nearly double that of the first.

As the speed at which a ship can traverse a certain distance depends upon the amount of coal carried, we arrive at this apparently paradoxical conclusion, namely, that for a constant weight of propelling machinery, the speed, within the radius of action, is as much greater as the maximum power of the engine is less.

Now let us consider the case of ships of different dimensions moving at the same rate of speed, and let us assume that for all of them the amount of coal carried A is the same fraction o of the displacement P; replacing A by oP in equation (9), the value of D can then be written :—

(12) $$D = \frac{o\, M_1^3}{C\, V^2} P^{\frac{1}{3}}.$$

Thus, if, on dividing up the various weights composing the displacement, we find that the total weight of coal carried is a constant fraction of the total displacement, the radius of action increases as the cube root of the displacement.

While high speeds do not necessitate a large displacement, a large radius of action does do so.

5. *Coefficient of Radius of Action.*—Replacing o by its value $\frac{A}{P}$ in equation (12), we obtain :—

(13) $$D = \frac{M_1^3}{C\, V^2} \frac{A}{P^{\frac{2}{3}}}.$$

The radius of action of a ship, assuming that V is constant, and that the variations of M_1 and C are negligible, is proportional to the ratio between the total amount of coal carried A and the two-thirds power of the displacement,

(14) $$N = \frac{A}{P^{\frac{2}{3}}}.$$

This quantity N is called the "coefficient of radius of action."

For warships which steam at greatly varying speeds it has been the custom for a long time in the French Navy to calculate the radius of action at a speed of ten knots, neglecting the consumption of coal required by the auxiliaries; under these conditions, assuming $M_1 = 5.75$ and $C = 1.78$ lbs., we have, taking the ton as unity:—

$$\frac{M_1^3}{C\,V^2} = 2016.$$

$$D = 2016\,N. \tag{15}$$

Assigning to N the three values, 0.75, 1.50, 3.0, which are very nearly those for coast-defence vessels, first-class battle-ships, and cruisers, we obtain for D the three following values, 1,533 miles, 3,068 miles, and 6,130 miles.

The special purpose for which a warship has been designed, is therefore more clearly shown by the coefficient N than by any other data.

Passenger boats carry a supply of coal proportional to the length of their voyage and their actual speed, but greatly exceeding the amount given by formula (13), so as to be prepared for any unfavourable weather they may encounter on their passage.

For short voyages, for instance between Algiers and Toulon, double the theoretical amount of coal is carried. For long voyages the excess is not so great; thus a Transatlantic liner, which burns in fine weather 1,700 to 1,800 tons of coal during the run from Havre to New York, carries in her bunkers 2,300 tons, which is about 33 per cent. in excess of the estimated consumption. Ships have been known to run short of coal as the result of meeting with persistent bad weather. The case may be cited of a passenger vessel, running from Colombo to Aden, which was caught in a north-west monsoon, and, after having accomplished more than two-thirds of the voyage, had to return with the help of her sails to Colombo in order to coal. This

example shows that the adoption of multiple screws cannot be regarded as a complete substitute for sails, unless care is taken to increase the supply of coal carried at the same time.

In the French Navy 10 per cent. more coal is allowed in commission than was burnt during the trials. This increase compensates for the difference in the quality of the coal, and in the skill of the stokers, but does not take into account the condition of the sea during a voyage. The effect of the state of the sea upon steam navigation will be returned to later on.

6. *Consumption of Coal by Auxiliary Machinery.*—The value of the coefficient N, which appears in formula (15), will be given for some of the boats already considered with regard to M and M_1; account has been taken in the calculation of N of the true values of M_1, of C, and, approximately, of the consumption of the auxiliaries. This last correction is important, for upon some battleships the auxiliary engines consume not less than $4\frac{1}{2}$ to $5\frac{1}{2}$ tons of coal per day. The correction is made in the following manner:—

Let q be the consumption of coal of the auxiliaries in tons per twenty-four hours; the ship being continually under steam the consumption per hour is one-twenty-fourth of this, which brings the consumption per mile run to—

$$\frac{q}{24\,V}$$

and the consumption for a distance D is—

$$\frac{q\,D}{24\,V}$$

Now

$$(15) \qquad D = 2016\,N$$

and the coal available for propulsion A is then reduced to—

$$(16) \quad A' = A - q\frac{D}{24\,V} = A - q\frac{2016\,N}{24\,V} = A - 84\,q\frac{N}{V}.$$

The value of N is consequently diminished and becomes N′:

$$(17) \qquad N' = \frac{A'}{P^{\frac{2}{3}}} = N - 84\frac{q}{P}\,\frac{N\,P^{\frac{1}{3}}}{V}.$$

The consumption q is nearly proportional to the displacement, so that we can write—

$$(18) \qquad \frac{q}{P} = 0.0005$$

which assumes a consumption of 1 ton of coal per day for a cruiser of 2,000 tons and 6 tons for a battleship of 12,000 tons.

Making at the same time $V = 10$ knots, we obtain—

$$(19) \qquad N' = N - 0.0042 \; N \; P^{\frac{1}{3}} = N \; (1 - 0.0042 \; P^{\frac{1}{3}}).$$

The coefficient of radius of action falls more rapidly the bigger the ship; it falls to 0.925 N for a ship of 11,600 tons displacement.

7. *Most Economical Speed.—Actual Radius of Action.*—The total consumption per mile, including that of the auxiliaries, is given by—

$$(20) \qquad \frac{F\,C + \frac{q}{24}}{V} = \frac{F\,C}{V} + \frac{q}{24\;V} = \frac{P^{\frac{2}{3}}\,V^2}{M_1^{\,3}}\,C + \frac{q}{24\;V}.$$

This consumption, by reason of the form of its two terms, will have a minimum value. The corresponding value of V, C and M_1 being constants, will be determined by the equation—

$$(21) \qquad 2\,\frac{C\;P^{\frac{2}{3}}}{M_1^{\,3}}\,V - \frac{q}{24\;V^2} = 0$$

from which, making $q = 0.0005$ P, $M_1 = 5.755$ and $C = 1.78$, we obtain, expressing C as a decimal of a ton—

$$(21a) \qquad V = \sqrt[3]{\frac{q\,M_1^{\,3}}{48\;C\;P^{\frac{2}{3}}}} = \sqrt[3]{\frac{M_1^{\,3}\;P^{\frac{1}{3}}}{96000\;C}} = 1.357\sqrt[9]{P}.$$

In reality the most economical speed depends chiefly upon the value of C, which is greatly increased for small values of V; and its determination requires the tracing of two separate curves, one for the consumption per mile of

the main engines, and the other for that of the auxiliary machinery (equation 20),

$$y = \frac{P^{\frac{2}{3}} V^2}{M_1{}^3} C \tag{22}$$

$$y_2 = \frac{q}{24\ V} \tag{23}$$

the second of which is a hyperbola.

With the sum of the ordinates y and y_2 a resultant curve can then be drawn and the horizontal tangent found.

In getting out the design of warships a distinction is made between the amount of coal required for the auxiliaries and that used in propelling the ship. In practice this separation cannot be made, since the ratio between the two consumptions varies with the speed on a voyage and the length of time the vessel is at anchor. During some commissions the consumption of the auxiliaries may reach 20 or even 30 per cent. of the total supply of coal on acconut of the amount consumed while at anchor.

D′ the radius of action at a speed of 10 knots, taking into account the consumption of the auxiliaries, has been calculated from formula (17) for the ships in the following Table:—

Name of Ship.	Data.				Calculated Coefficients.					
	P	A	M_1	C	I	N	IN=D	N′	IN′=D′	F
	Tons.	Tons.		lbs.						
Carnot	11,955	689	6·506	1·65	3,730	1·318	4,916	1·191	4,443	1,898
Charles Martel	11,689	646·7	6·586	1·76	3,634	1·255	4,561	1·135	4,126	1,802
Brennus	11,192	600·4	6·406	2·12	2,775	1·199	3,327	1·086	3,015	1,897
Magenta	10,678	605·3	6·314	2·07	2,717	1·248	3,391	1·113	3,024	1,927
Cocyte	1,687	70·9	5·551	2·09	1,822	0·5	911	0·475	865	829
Dupuy-de-Lôme	6,477	885·8	5·925	1·67	2,781	2·548	7,085	2·346	6,508	1,670
Isly	4,404	571·8	6·061	1·36	3,643	2·127	7,748	1·979	7,190	1,204
Friant	3,679	575·7	5·755	2·06	2,061	2·415	4,978	2·216	4,567	1,251
Lavoisier	2,200	224·4	6·326	1·92	2,950	1·327	3,914	1·255	3,701	668
Lalande	1,895	283·4	5·802	2·05	2,126	1·85	3,933	1·753	3,727	785
Lévrier	496·4	93·5	4·846	1·65	1,542	1·491	2,299	1·441	2,222	551
Durandal	297·2	37	5·785	1·94	2,232	0·83	1,854	0·807	1,802	230
Chevalier	132·1	15·7	4·979	0·80	3,439	0·618	2,157	0·604	2,077	210
Forban (*at* 14 *knots*)	149·7	17·7	5·598	0·85	2,340	0·63	1,470	0·614	1,437	441
Cyclone (*at* 14 *knots*)	101·3	17·1	5·344	0·84	2,053	0·78	1,614	0·771	1,583	392
Torpedo Boat 203 (*at* 14 *knots*)	83·4	10·3	5·325	0·91	1,884	0·54	1,027	0·535	1,008	344

The displacements given in this Table are taken from the finished designs of the boats prior to construction, and this explains why they do not quite agree with the figures in the Table on page 7, which was compiled from the figures obtained on the official trials. For the estimated displacement of 6,200 tons the coal supply A of the *Dupuy-de-Lôme* is only 609 tons, corresponding to a value of $D'=4{,}500$; a similar remark applies to several of the ships referred to in the Table, the coal supply given being in excess of the actual amount carried.

In order to show the practical application of formula (15) to different types of ships in the French Navy, a Table is inserted giving the distance in sea miles between two of the principal naval ports of France and the foreign stations usually visited by French warships. The speed assumed is 10 knots.

From Cherbourg to—	Miles.	*From Toulon to—*	Miles.
Brest	189	Funchal	1316
Dunkerque	161	Santa Cruz	1418
Wilhelmshaven	478	St Louis	2159
Hamburg	524	Halifax	3375
Christiania	760	New York	3384
Kiel	917	Fort de France	3950
Dantzig	1118	Rio Janeiro	5012
Riga	1303	Cape Town	5913
Cronstadt	1549	Buenos Ayres	6012
Funchal	1282	Alexandria	1323
Santa Cruz	1498	Massowah	2535
St Louis	2271	Colombo	4924
Halifax	2524	St Pierre	5282
New York	3066	Pondicherry	5530
Fort de France	3950	Saigon	7150
Rio de Janeiro	5012	Hong-Kong	7885
Cape Town	5913	Yokohama	9858
Buenos Ayres	6012	Sydney	9746

From Toulon to San Francisco	13,468 miles by the	Cape of Good Hope.
	13,231 ,, ,,	Straits of Magellan.
From Brest to Nouméa	12,759 ,, ,,	Cape of Good Hope.
From Dunkerque to Foo-Chow	13,347 ,,	

These Tables enable the radius of action of a fleet to be easily determined.

It will readily be seen that ironclads cannot make the return voyage to Alexandria, coast-defence vessels to Kiel, and cruisers to New York or Halifax, even if it is assumed that the ship travels direct there and back, without carrying out any military operations or manœuvres. It is for this reason that sails have been preserved as an auxiliary source of motion upon some of our battleships, and it explains why, even upon passenger ships, masts are still carried, though they are practically of little value in time of peace owing to the facilities for re-coaling.

Sails, in comparison with steam, form a very light source of motive power. Their total weight on a large ship scarcely ever exceeds 10.2 lbs. per square foot of sail area, or 307 lbs. per square foot of midship section. This is equivalent, at 6 knots, to an engine of 0.32 horse-power per square foot of midship section, which would formerly have weighed 0.49 ton without the coal, and to which must be added 0.49 ton per 1,000 sea miles run at 6 knots. Under these conditions sails have the superiority over steam for distances of over 2,000 sea miles, and they are still retained for merchant ships making long voyages.

8. *Curves and Tables of Horse-power, Consumption, etc.*—The application of algebraical formulæ such as (6) and (13) to the calculation of the general problems in ship propulsion is a very useful method of arriving at an approximate solution of the questions involved. As soon, however, as we consider the case of a ship moving at a variable rate of speed, we can no longer assume that the coefficient of performance M_1, the consumption per horse-power C, and consequently the coefficient of radius of action N, are constants. We must therefore have recourse to curves giving the actual conditions of working at various speeds.

In practice these curves are supplied with the drawings of each boat. Taking the revolutions as the abscissæ,

speed, horse-power, coal per hour and coal per horse-power hour, are plotted as the ordinates. Four curves are thus obtained from which the curves giving the coal burnt per mile and the coefficients of performance and radius of action are easily deduced.

The following Table gives the results obtained from the coast-defence vessel *Indomptable* which have served as a basis for the designs of other ships.

Revolutions per Min.	Speed in Knots. V	Horse-Power. F	Consumption of Coal.	
			Per Hour.	Per Horse-Power-Hour. C
			lbs.	lbs.
30	5·51	276	1,270	4·6
40	7·41	561	2,215	3·95
50	9·12	1,034	3,472	3·36
60	10·92	1,800	5,173	2·87
70	12·58	2,985	7,374	2·47
80	14·05	4,721	10,570	2·24
90	14·96	7,067	19,610	2·77

The readings given in this Table lead to the two following deductions.

In the first place, the consumption of coal per horse power, which varies irregularly for speeds between 11 and 15 knots, is double at 5 knots to what it is at 14 knots. The formulæ for the radius of action are therefore only applicable to slow speeds when giving to C values that have been determined by actual experiment.

In the second place, the speed V is practically proportional to the revolutions n; or, in other words, the forward movement of the ship for each revolution of the screw is constant whatever be the speed. This last remark is specially important, as the approximate rule that it enunciates is universal and holds for all ships at any rate of speed, on the assumption, of course, that the sea is calm. In a rough sea the advance of the ship per turn of the screw diminishes considerably. This is the reverse of what

takes place with a paddle-wheel, where it is always fairly constant.

The preceding rule can be expressed under another form. The speed V being proportional to n, and also proportional to the cube root of F, equation (6), the horse-power F is proportional to n^3. But, on the other hand, the horse-power F is proportional to the product $n\,p$, of the revolutions n and the mean pressure on the pistons. It follows at once from this that the square of the revolutions of the engine varies as the pressure p.

This law, which can be expressed thus—

$$\frac{n^2}{p} = \text{constant},$$

is of a more general character than that relating to the constant forward motion of the ship per revolution, as it is independent of the condition of the sea ; when the ship loses speed the screws continue to revolve, on account of the pressure p on the pistons, very much as they would do in a calm sea.

The coefficient of performance M_1 of a screw steamer decreases more rapidly from the effect of a heavy sea than does that of a paddle steamer, whose engines are not so liable to race, and the consumption of coal per mile run is greater for bad weather. This difference, which is of little real importance, was at one time brought forward as a strong point by the advocates in favour of the slower paddle boats, and with good effect.

The Table showing the results obtained from the *Indomptable* can easily be completed by the addition of the consumption per mile, the radii of action being calculated on the assumption that out of a total weight of 394 tons, 354 tons are available for the main engines, and also by the addition of the coefficients of performance M and M_1 calculated respectively from the values of B^2 and P during the trials.

We then obtain the following Table :—

Revolutions per Min. n	Consumption of Coal per Mile.	Radius of Action. D	Coefficients of Performance.	
			M	M_1
	lbs.	Miles.		
30	230·6	3,487	9·150	6·132
40	298·9	2,690	9·704	6·508
50	380·7	2,112	9·746	6·535
60	473·5	1,697	9·692	6·500
70	586·1	1,371	9·442	6·331
80	752·2	1,069	9·052	6·069
90	1,310·5	613	8·431	5·654

§ 3. REGULARITY OF SERVICE.

9. *Effect of Pitching upon Speed.*—After the discussion of the question of speed and the radius of action, it may not be out of place to say a few words in regard to regularity of service, which was one of the greatest advances made in navigation due to the substitution of the steamship for the sailing vessel.

This regularity of service is particularly noticeable in the large passenger steamers of 10,000 to 25,000 tons displacement, which, standing as they do high out of the water, have everything arranged so as to ensure their making a quick passage in all weathers. This regularity is also sufficient, on large cargo steamers, to compensate for the increase of their freight charges over those of sailing ships. Upon men-of-war the size of the ship and the particular shape or form imposed by the purpose for which the ship was designed, make good behaviour in all weathers of lesser importance.

The efficiency of the screw drops enormously as it emerges from the water, and as it enters the water again, it draws down with it a large quantity of air, and hence works at a very low efficiency in an emulsion of air and water. The speed of the ship would any way be reduced

even supposing the engines continued to run at their ordinary revolutions, but on account of the enhanced risk of break-down the revolutions are purposely reduced. There are two reasons for making a reduction in speed of the vessel desirable: First, there is the risk of striking a big sea, and second, the risk of accident to the engines.

Ships must satisfy two conditions in order to preserve their speed during rough weather. In the first place, their bows must be high and fine in order to prevent the heaping up or shipping of too much water. In rough weather it is to be expected that at each dip a few tons of water will be taken on board, but this will easily run off through the scuppers. In the second place, in order to ensure a good immersion of the screw—this is absolutely necessary—it is important to have a considerable draught of water at the stern.

Large cruisers, that is to say those of from 8,000 to 14,000 tons, have a regularity equal to liners. At about 6,000 tons the state of the sea has an appreciable effect. In order to be certain of an average speed of twelve knots in all weathers a displacement of not less than 3,000 tons is needed. Below 1,500 tons a ship can no longer be absolutely relied upon for scouting purposes. The whole of the long series of catchers and torpedo-boat destroyers can only be relied upon with certainty in fine weather.

It would be interesting to know the number of days during the year in which the operations of any particular type of warship have been interfered with or hindered by the state of the sea; unfortunately no such data are obtainable.

CHAPTER II.

SHORT DESCRIPTION OF VARIOUS TYPES OF BOILERS.

10. *General Considerations.* — The engine on board ship is often subjected, as a whole, as well as in detail, to severe strains.

The weight being limited to a given fraction of the displacement, lightness assumes an importance quite unknown in land engines. The maximum power that can be obtained from a given weight varies inversely as the weight of the machinery per horse-power; hence the great importance of this factor on the general value of the vessel. Further, economy in coal consumption on board ship is not merely a question of so much money saved. It is of much greater importance; it means a greater steaming distance with a given coal capacity, or a reduction of bunker space, which again in its turn means increased freight-earning capacity, or increased armaments, as the case may be.

Lightness in boilers is primarily obtained by a reduction in the weight of water and by the adoption of forced draught, although the reduction of weight realisable by attention to the smaller details must not be lost sight of. Forced draught has but little *raison d'être* on land, but is extensively used on board. It is possible to double, or even quadruple for a short time, the power of a boiler by means of forced draught, and the high speeds obtained, in the first instance on board torpedo-boats, and subsequently on board larger boats, was largely due to the application of forced draught.

The search for lighter engines led to the adoption of higher pressures, but in this case the advantages must be viewed in relation to the weight of machinery and coal as a whole, and not in relation to the boilers alone, as the weight of the actual boilers increases with the pressure.

Over and above the question of lightness, the space available on board for boilers is often very limited. They must be capable of being shipped on board without necessitating hatchways of excessive dimensions. They must be durable, as simple as possible, and capable in all cases of steaming long distances without undergoing repairs, or the daily inspection required by locomotive boilers. Inspection ought to be possible entirely from the front of the boiler, which is generally the only side of the boiler at all easily accessible, and what small repairs may happen to be necessary should be able to be carried out with the means usually available on board ship.

Marine boilers are exposed, especially during manœuvres, to sudden changes in the rate of working, which often give rise to straining, and severely tax the elastic properties of the boiler.

With so many conditions to be fulfilled, it is not astonishing that the ideal boiler has not yet been discovered.

The arrangement of the boiler on board has to be carefully thought out and considered. Allowance must be made for the protection of the neighbouring parts of the vessel from heat, for ensuring a sufficient supply of air to the furnaces, and for a sufficiently rapid supply of coal to the stokehole.

There are other details, such as getting rid of the ashes, which, though insignificant on land, assume considerable importance on board ship. These are more properly questions of ship construction, and we will content ourselves by merely calling attention to them in passing.

§ 1. CLASSIFICATION OF BOILERS.

11. *Flue Boilers.*—For a long time marine boilers belonged to the class known as internal flue, or internal combustion

Vertical section on *yy*.

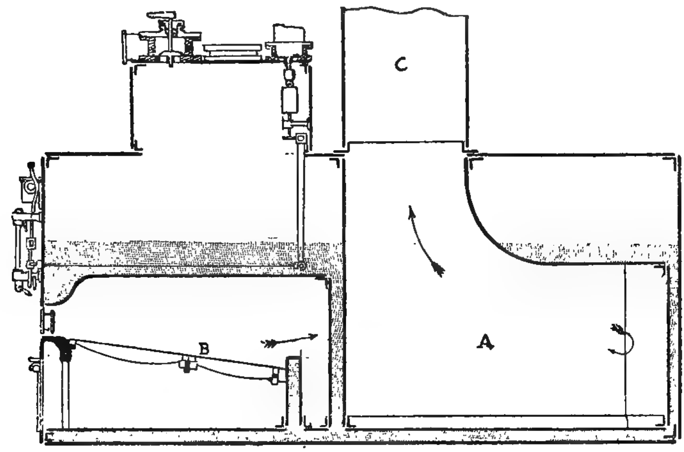


Fig. 4.

Half elevation and half section on *xx*.

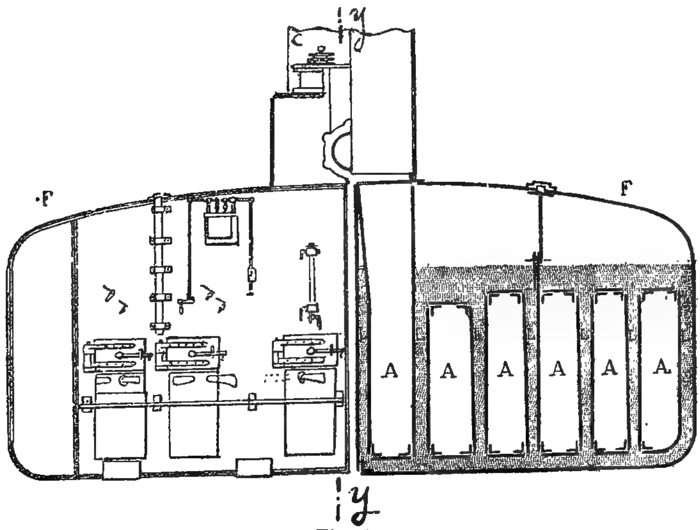


Fig. 4A.

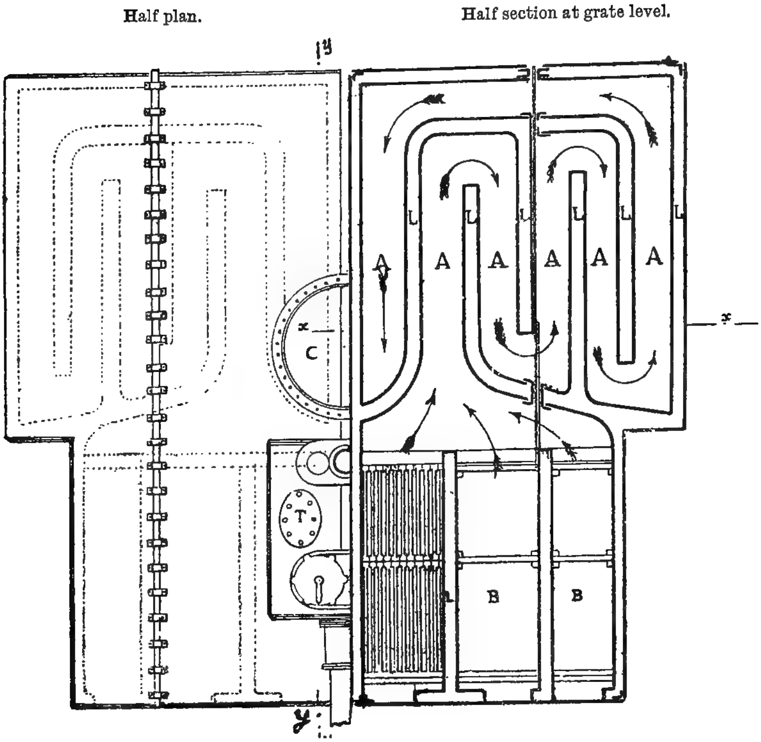


Fig. 4B.

A. Flame passages. B. Grate. C. Funnel.
LL. Water Spaces. T. Manhole.

Boiler Pressure . .	3·5 lbs. per square inch.
Grate Surface. G. .	41·4 square feet.
Heating Surface. S .	915 square feet.
Ratio $\frac{S}{G}$	22·1.

boilers, of which there have been many varieties since the Cornouailles boiler, which is the oldest type of all. This type of boiler, which possesses advantages from the point of view of economy in combustion, was specially applicable to wooden vessels on account of its enhanced security against fire. It is characterised by the presence on all its sides of

water spaces completely enveloping the furnaces and flame passages.

The earlier models, with the low boiler pressures then in vogue, were simple boxes of a parallelopiped form, where the flames circulated through large square passages with flat sides entirely immersed in the water, the top part of the boiler forming the steam space. (Figs. 4, 4A, 4B.)

12. *Tubular Boilers—Box Type.*—The first marked progress made in boiler construction consisted in the introduction of tubes of small diameter, dividing up the hot gases and increasing the heating surface.

The box-shaped passages were replaced by a nest of tubes, surrounded by water, through which the hot gases passed.

The course taken by the gases was from the furnace to the combustion-chamber, which might be common to several furnaces, through the nest of tubes to the smoke-box, and so to the funnel. This class of boiler was used for a long time in the French Navy. (Figs. 5 and 5A.)

Sometimes the box-shaped passage was retained, only filled up with a nest of vertical tubes, around which the flames passed on the outside, the water being on the inside.

This boiler, known as the Martin or Cochrane boiler (Figs. 6 and 6A), was adopted on several English passenger steamers, on the *Vanguard*, and in the American Navy.

13. *Cylindrical Boilers.*—The rectangular form of boiler, though well adapted to the form of the stokehold, had to be abandoned when higher pressures were adopted.

There were numerous attempts about this time to make boilers consisting of a simple nest of tubes and reservoirs attached, all heating being external; but these attempts had to be abandoned, and boilers of large volume, similar to those at present in use, known under the name of marine

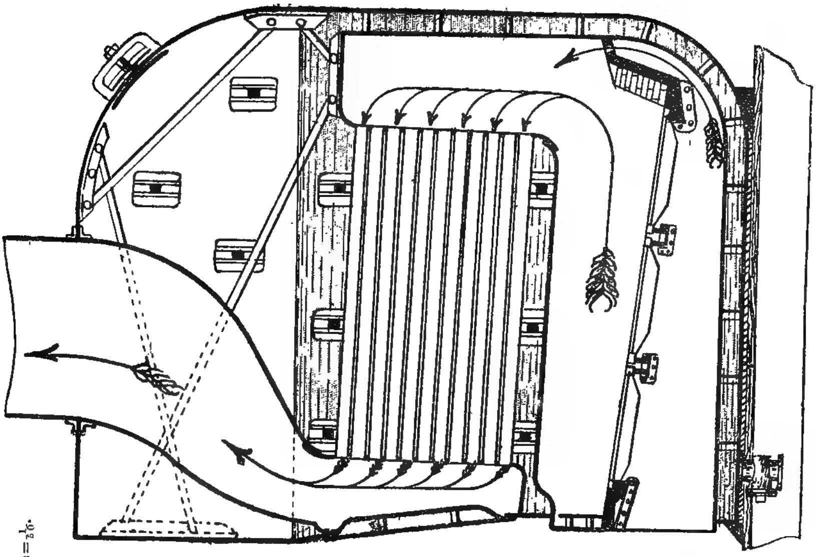


Fig. 5A.

BOX TYPE OF BOILER
(1858-1870).
Scale—2 cm. = 1 mètre = $\frac{1}{50}$.

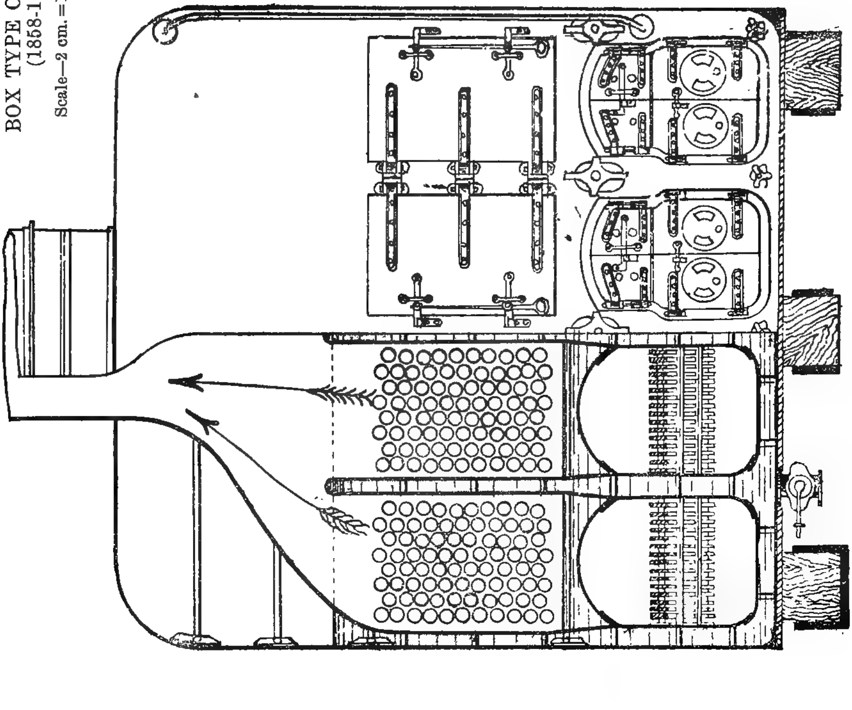


Fig. 5.

boilers or Scotch boilers, because they were first used on the Clyde, came into use.

Cylindrical boilers, due to their form, stand the higher pressures better, and only need staying in one direction instead of in three. The great drawback to the cylindrical form was the amount of water it contained, whereas with rectangular boilers, largely composed of water-spaces, of which it was much easier to regulate the thickness, the total

MARTIN OR COCHRANE BOILER.

Scale—1 cm. = 1 mètre = $\frac{1}{100}$.

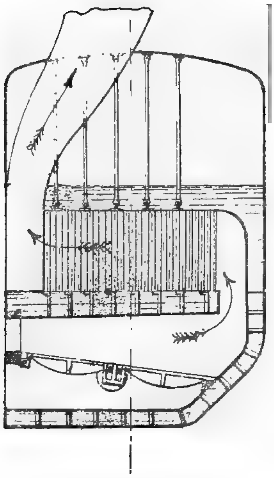


Fig. 6.

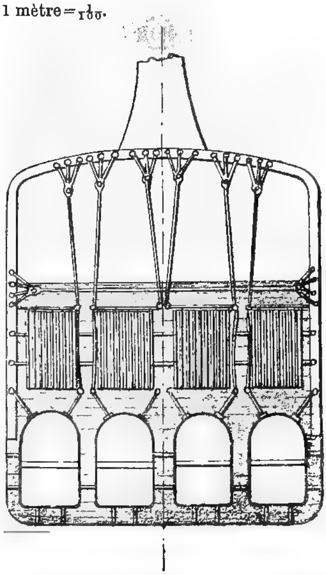


Fig. 6A.

quantity of water contained could be considerably reduced. Cylindrical boilers are made with one, two, three, and four furnaces. Those having three or four furnaces have them at different heights from the stokehold floor; Figs. 7 and 7A show boilers with two furnaces; Figs. 8 and 8A, three furnaces. The same internal arrangements are met with as in the rectangular boiler, consisting of furnaces, combustion-chambers, a nest of tubes and smoke-box,

and the flat water-spaces met with round the combustion-chamber are similar in both cases.

Cylindrical boilers are made single and double ended; the latter, shown in Figs. 9 and 9A, 10 and 10A, may have as many as eight furnaces. This arrangement is adopted to save weight and space.

Boilers of elliptical form were also tried, but were abandoned on the introduction of higher pressures.

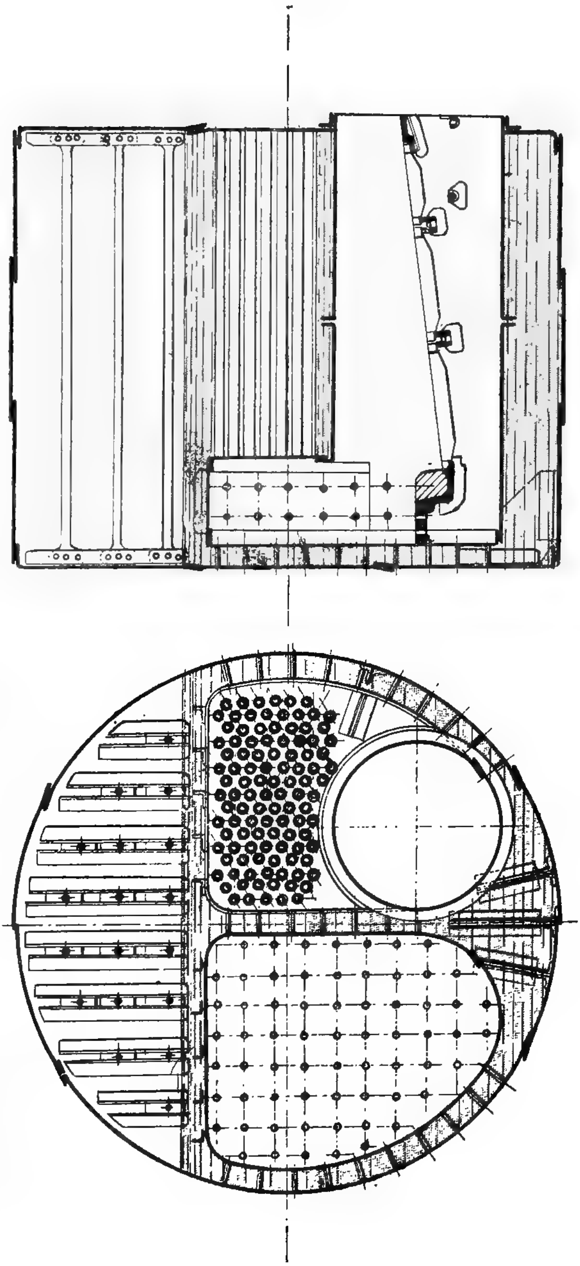
The cylindrical type is that now almost universally adopted in the mercantile marine, but on account of the small amount of head-room available on some men-of-war, in order to reduce the diameter, the tubes were placed as a continuation of the furnace, the combustion-chamber being between the furnace and tubes. This type had a large amount of water in the neighbourhood of, and surrounding the furnace, and so exaggerated the difficulty with regard to weight, which elliptical boilers had been primarily designed to lessen.

14. *Locomotive Boilers.*—The necessity of reducing the amount of water led to the introduction of the locomotive type of boiler, in which the large rectangular furnace is surrounded by flat water-spaces, and the combustion-chamber is entirely done away with. These boilers gave very good results on board the torpedo-boats when in the hands of thoroughly experienced persons, but they were not able to stand the long runs to which they would have been subjected on ordinary boats.

15. *Tubulous Boilers.*—The introduction of still higher pressures and the necessity of cutting down weights, especially in the navy, led to the introduction of boilers composed entirely of tubes filled with water and steam. Boilers composed of tubes, or tubulous boilers, have replaced the locomotive boilers on torpedo-boats, and are being

STANDARD CYLINDRICAL BOILER (1875).

Scale—2 cm. = 1 mètre = $\frac{1}{50}$.



Half section through the furnaces.

Half section through the combustion chamber.

Fig. 7A.

Fig. 7.

JEAN-BART

CYLINDRICAL RETURN-TUBE BOILER.

Scale—2 cm. = 1 mètre = $\frac{1}{50}$.

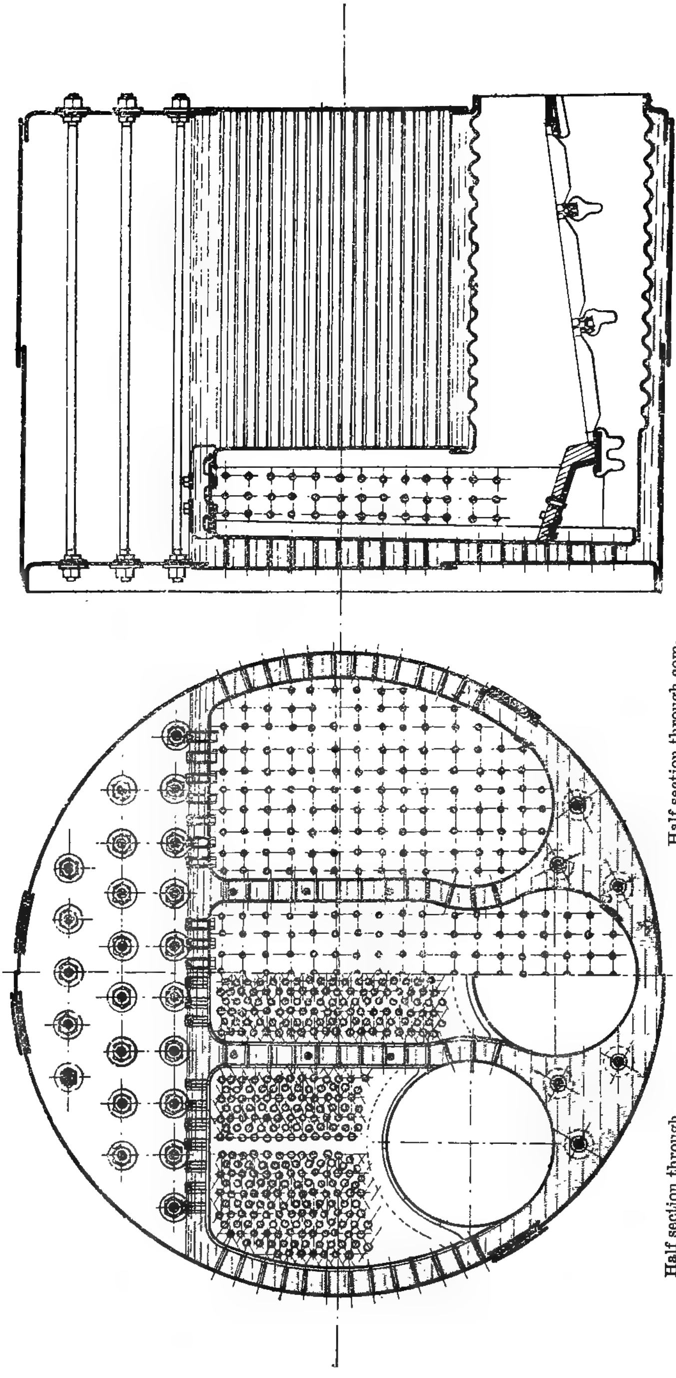


Fig. 8A.

Half section through combustion chamber.

Half section through furnaces.

Fig. 8.

CÉCILLE

DOUBLE-ENDED BOILER.

Scale—15 mm.=1 mètre.

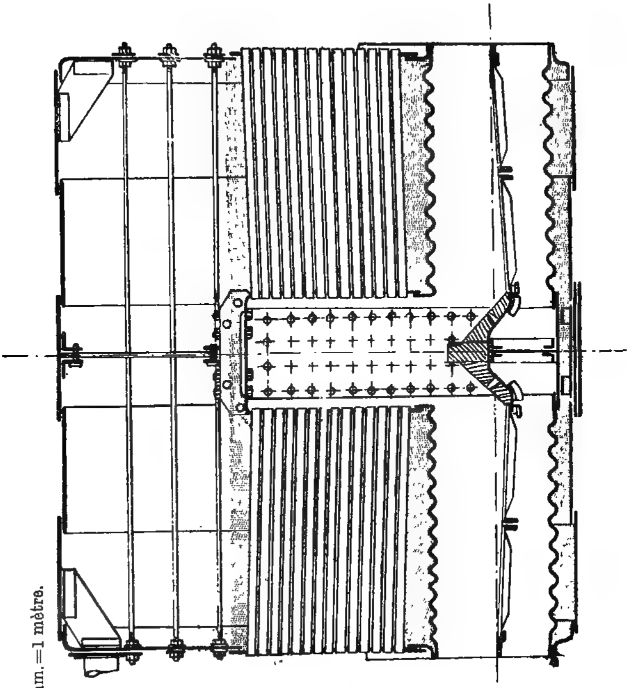


Fig. 9A.

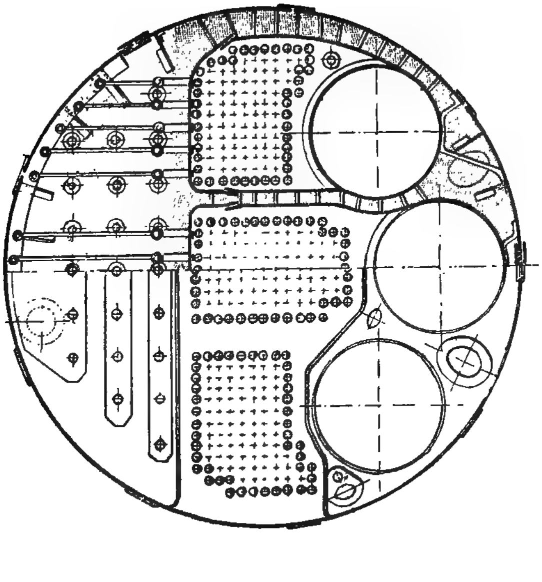


Fig. 9.

D'ENTRECASTEAUX

DOUBLE-ENDED BOILER.

Scale—15 mm.—1 mètre.

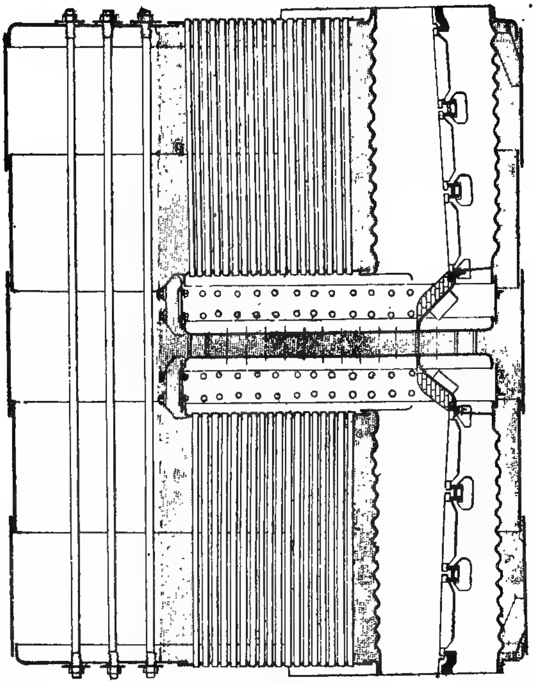


Fig. 10A.

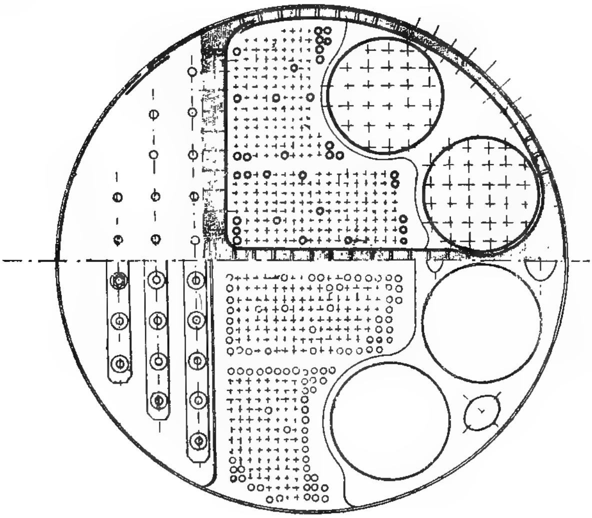


Fig. 10.

MARCEAU.

ADMIRALTY OR DIRECT-TUBE TYPE.

Scale—15 mm.=1 mètre.

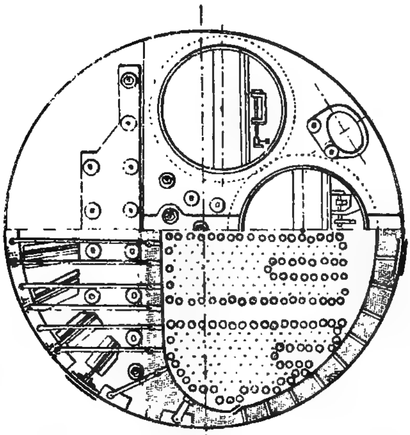


Fig. 11A.

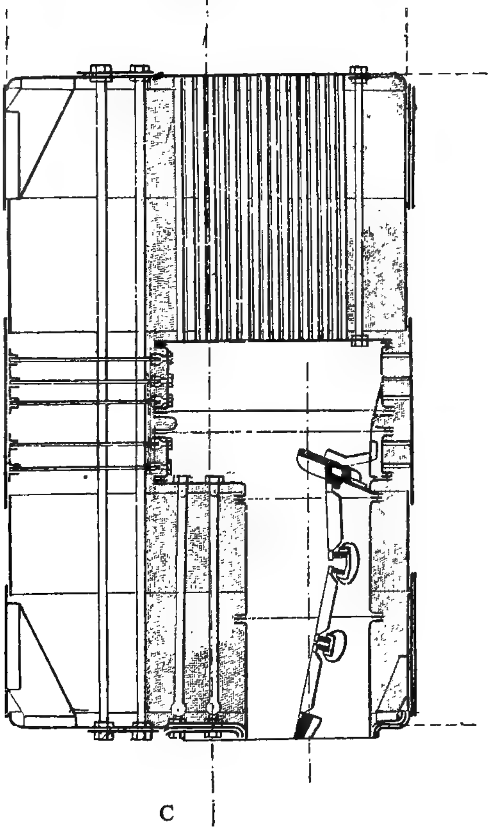


Fig. 11.

C

extensively used on despatch-boats, and cruisers in the French and other navies. The Messageries Maritimes have also adopted the oldest and best known type of tubulous boiler, the Belleville boiler, on their passenger steamers.

The different types of tubulous boilers are so numerous that we cannot do more than give a general description of them, as we did of cylindrical boilers. In our more detailed examination we shall divide them into three distinct groups.

TORPEDO-BOAT LOCOMOTIVE BOILER (TYPE B).

Scale—15 mm. 1 mètre.

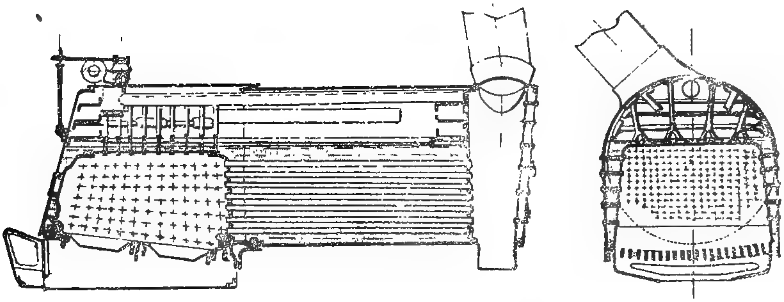


Fig. 12. Fig. 12A.

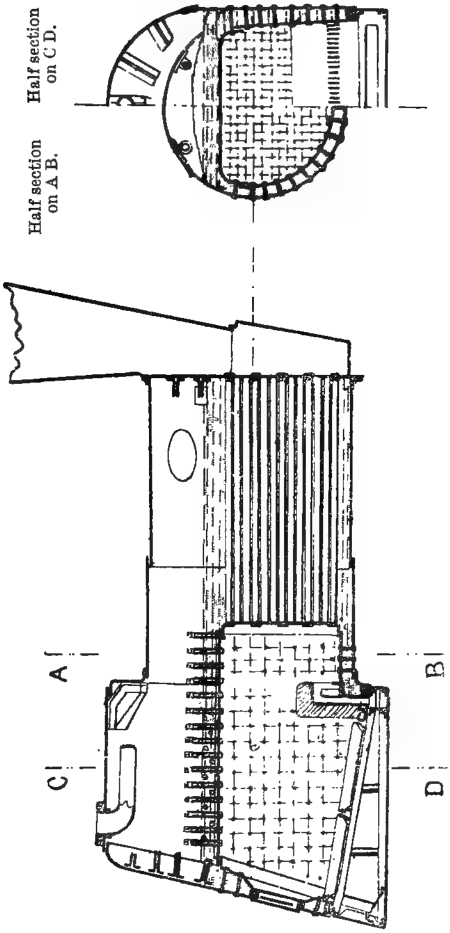
(*a*) *Boilers with Limited Circulation*, that is, serpentine or coil boilers, in which there is no circulation except that necessary to replace the water evaporated. The generating tubes, arranged more or less in the form of a coil and composed sometimes even of a single tube in a helical form surrounding the furnace, receive the feed-water at one end and discharge the steam at the other.

The Belleville boiler is the best known boiler of this type.

(*b*) *Boilers with Free Circulation.*—The chief characteristic of these is the presence of a vertical flat water-space at the front and back of the boiler connected by horizontal or slightly inclined tubes.

These tubes receive the water from one reservoir and

discharge it into the other as steam. The current is, as a rule, much more active than in the previous case, and the steam gets away much more freely. The best-known boilers



LOCOMOTIVE BOILER (FLAMME TYPE).

Scale—15 mm.=1 mètre.

Fig. 13A.

Fig. 13.

in France of this class are the Oriolle, D'Allest, and Niclausse.

(*c*) *Boilers with Accelerated Circulation, or Boilers with Horizontal Reservoirs placed at different heights.*—This class

MILAN.

BELLEVILLE BOILER.

Scale—15 mm.=1 mètre.

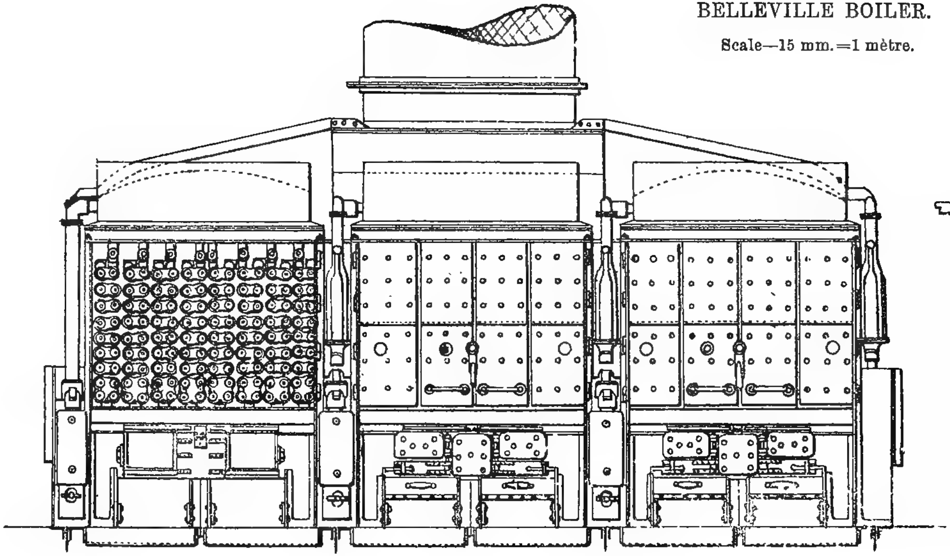


Fig. 14.

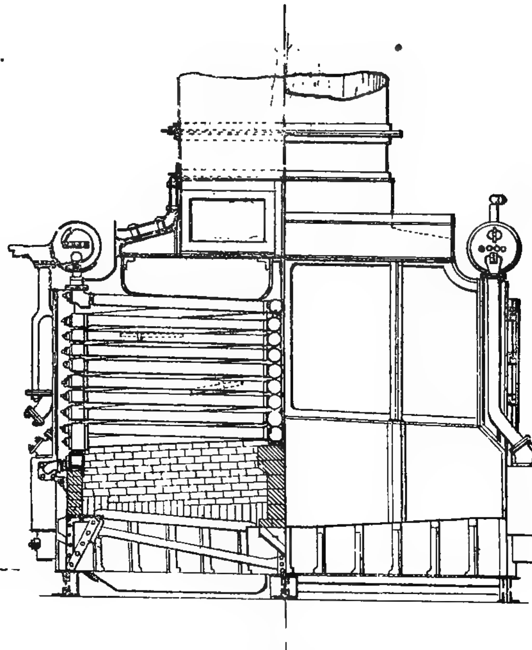


Fig. 14A.

of boiler is characterised by the direction given to the water, which is as nearly vertical as possible in its passage between

JAURÉGUIBERRY.

GENERAL VIEW OF A GROUP OF TWO LAGRAFEL AND D'ALLEST BOILERS.

Scale—18 mm.=1 mètre.

Front elevation. Transverse section. Longitudinal section.

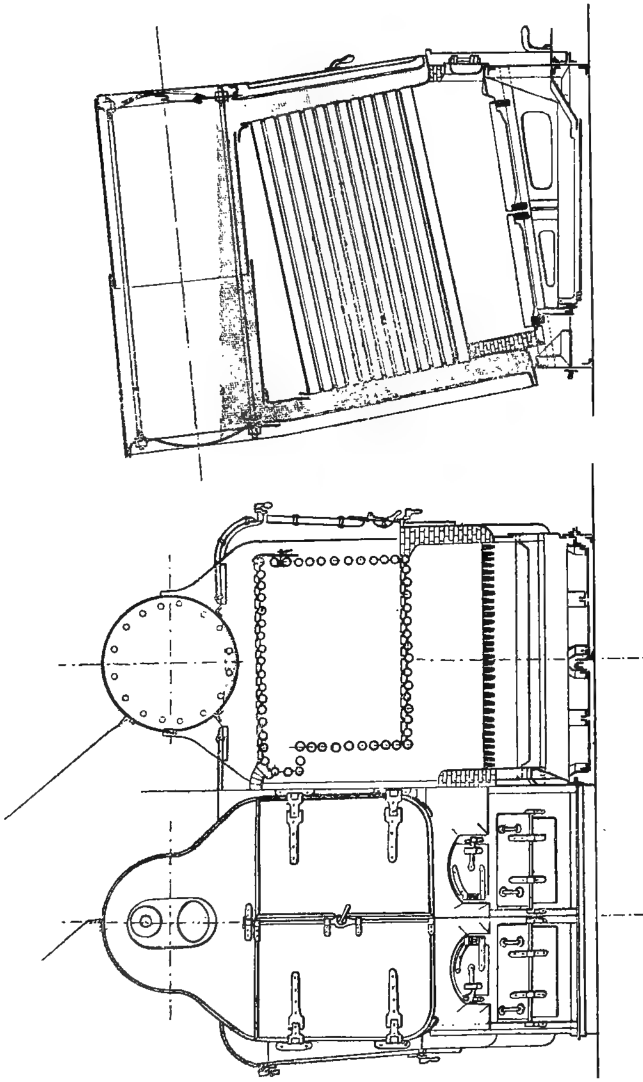


Fig. 15. Fig. 15A.

the reservoirs. Large down-take tubes return the water from the top steam drum to the lower water drum.

Everything is thus arranged to facilitate a continued and general circulation.

The typical boiler of this class is the Du Temple boiler, from which have sprung the Thornycroft, Normand, and other boilers. This classification into three distinct groups does not hold universally, as there are some intermediate types which it is very difficult to classify. They naturally fall into this classification from their general arrangement and mode of working.

TORPEDO-BOATS, Nos. 172 to 176.

DU TEMPLE BOILER.

Scale—15 mm.=1 mètre.

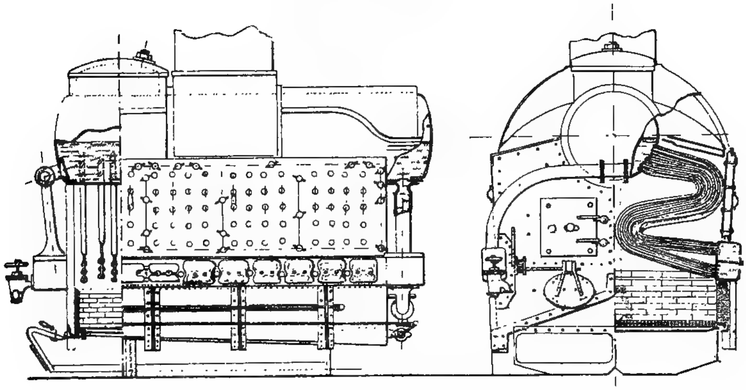


Fig. 16. Fig. 16A.

The boilers of the first two classes are now being extensively used on shore, where they are entering into competition with the old cylindrical boiler, and have the advantages of greater immunity from danger of explosion; they are also fairly economical at the low rates of working at which they are run on shore.

The tubulous boilers of the third class are specially adapted to the requirements of the navy.

§ 2. NOTES ON THE GENERAL BEHAVIOUR OF BOILERS.

16. *Boiler Fittings.*—A boiler is really in principle a simple piece of apparatus, although it may be of delicate construction and may need careful handling to obtain the best results. It consists of a chamber for the flames and a reservoir for the water placed next to one another, and it is difficult to discern beyond these any well defined or distinct organs. The flame chamber commences with the furnace, which consists of two parts, the furnace and the ashpan, separated from one another by the grate. It is followed by a combustion-chamber often difficult to distinguish from the flame passages, and it terminates in the smoke-box.

The water and steam reservoir, which is the boiler properly so called, always fulfils the same function whatever its form. It is sometimes fitted with a settling drum, where the solid matters contained in the water are deposited, and at the top a steam receiver, which enables the steam to be taken off well above the water-level.

The various parts of the boiler are stayed as occasion requires, and manholes are fitted for cleaning and inspection.

The boiler mountings are numerous and often complicated.

The funnel by creating a draught draws the air into the furnaces. It is a very simple, though not a very economical way, of procuring the necessary air for combustion.

To reduce the likelihood of accidents, there are nearly always two distinct systems of feed, one by the feed-pump in the engine-room and one by the donkey-pump in the stokehold.

Each system has its own piping, and must be capable of supplying all the water that may be required by the boiler. The feed-pumps are designed for ordinary use, and are under the control of the engineer in the engine-room ; the donkey-

pumps are only a stand-by in case of need, and are controlled by the stokers. The main feed-pumps are also occasionally placed in the stokehold. The feed system comprises all the fittings for purifying and heating the feed-water, questions which are daily growing in importance and receiving more attention. Means for injecting lime into the feed-water are now usually fitted.

A very important fitting, especially on warships, is the fan, which allows the draught to be varied at will independently of the funnel.

Several attempts have been made to use mechanical stokers, but so far without success. The only case where it has been successful is with liquid fuel.

To the above may be added those fittings more especially useful to increase the safety or security of the boiler; they are pressure-gauges, safety-valves, low-water alarms, water-gauges, and test-cocks. Float feed-regulators are also used to regulate the feed.

Lastly, there is the steam stop-valve and all the piping which may be considered an adjunct either to the boiler or the engines. Each boiler has its own stop-valve to enable it to be shut off at will from the rest of the boilers.

The steam piping, with all its subsidiary fittings, such as valves, expansion joints, traps, separators, is daily becoming more and more complicated. The complications introduced into the steam piping of the navy form a striking contrast when compared with that of the mercantile marine, even where the duties to be performed by the piping are more or less the same.

CHAPTER III.

BRIEF DESCRIPTION OF MARINE ENGINES.

§ 1. GENERAL CONSIDERATIONS.

17. *Working Conditions of Marine Engines.*—The marine engine and boiler being so closely connected together, and forming as a whole the propelling machinery of a vessel, some brief elementary remarks on marine engines may not be out of place.

The conditions under which a marine engine is called upon to work are different in many respects from those obtaining in land engines; for instance, the question of weight and consumption of steam are of very much greater importance in the first case than they are in the second.

The speeds of marine engines are, as a rule, higher, since, by increasing the revolutions of the engines, their power may be augmented without at the same time proportionally increasing their weight. This bears a close analogy to the use of forced draught for increasing the power of a boiler.

By increasing the boiler pressure and expanding the steam successively in two, three, or more cylinders, economy in steam consumption has been realised.

Marine engines are always condensing engines, which, from an economical point of view, is in their favour. For land engines, it is frequently impossible, for want of circulating water, to secure this advantage.

The facilities for manœuvring the engines, stopping, starting, reversing, etc., have to be much greater on marine engines, as the exigencies of navigation and war render this imperative. The screw having now entirely replaced the paddle in the mercantile marine, except in the case of a few river and cross-channel steamers, and having completely done so in the navy, the screw engine only need be dealt with.

§ 2. CLASSIFICATION OF ENGINES.

18. *Vertical Engines.* — Vertical engines, with their cylinders directly over their shafting, are universally used in the mercantile marine, where there is never any want of head-room. The greater facility they afford for inspection while running has led to their general adoption in the navy.

To economise floor space, tandem engines, with their cylinders one on top of the other, are sometimes adopted in the mercantile marine.

On warships, the necessity of protecting the engines, either by keeping them under the armoured deck, or under the water-line, led to the introduction of the horizontal type. The horizontal engine has, however, been gradually abandoned in favour of the vertical engine.

19. *Horizontal Engines.* — Various kinds of horizontal engines were adopted, such as the trunk engine, return connecting-rod, etc., all of which are too well known to need detailed description here.

20. *Nomenclature Employed.*—The cylinder receiving the high-pressure steam from the boiler is always known as the high-pressure cylinder, that exhausting into the condenser as the low-pressure cylinder. In a triple-expansion engine, the cylinder between the high- and low-pressure is

known as the intermediate cylinder, and in the case of a quadruple-expansion engine, the two cylinders between the high-pressure and low-pressure are known as No. 2 and No. 3 cylinder; the end of the cylinder nearest the crank is known as the bottom of the cylinder, and the opposite end as the top of the cylinder.

§ 3. THE PRINCIPAL PARTS OF THE ENGINE.

21. *Course of Steam through the Engines.*—The steam enters the engines through the main stop-valve and throttle-valve.

This latter valve, which is of great service to the engineer in manœuvring his engines, can also be used as a primitive kind of reducing valve.

The steam then passes direct into the high-pressure valve casing, which may or may not be fitted with an expansion valve. The reversing engine, fitted on large marine engines for reversing purposes, is also used to vary the expansion of the steam in the cylinders. Slots are generally provided on the levers fitted to the way-shaft to enable the expansions in the different cylinders to be altered independently within certain limits.

After passing through the cylinders, the steam is exhausted into a surface condenser, which is a necessity, on account of having to feed the boilers with fresh water; and this is a matter of the very greatest importance with tubulous boilers, as we shall see further on. The various pumps, such as circulating-pump, feed-pump, air-pump, etc., need not be dealt with here.

22. *Moving Parts of Engine.*—A few of the various moving parts of the engine may be enumerated, though they cannot be described in detail. The piston-rod is fitted into the piston and passes through the stuffing-box, being

fitted at the end with a cross-head and guide-slipper. The connecting-rod is attached at its upper end to the cross-head, and its lower to the crank-pin. The shafting consists of crank-shaft, thrust-shaft, intermediate lengths, and tail, or propeller shaft. This latter passes through the stern-tube, and carries on its outer end the propeller boss, to which the screw blades are attached. The thrust-block takes up the thrust of the propeller and transmits it to the hull of the vessel. The slide- and piston-valves distributing the steam to the various cylinders are driven by eccentrics off the crank-shaft. Various kinds of valve-gear, both of single and double eccentric types, have been adopted, but the simplest and most largely used is the ordinary Stephenson double-link motion.

A small auxiliary engine is usually fitted for turning the engine in port when under repairs.

For more complete details of this subject the reader is referred to the Editor's English edition of Dr Bauer's "Marine Engines and Boilers."

CHAPTER IV.

PRODUCTION OF HEAT FROM COAL.

§ 1. GENERAL CONSIDERATIONS.

23. *Boiler Efficiency.—Total Heat Tables.*—The quantity of water evaporated in a boiler is always a matter of the greatest importance, and determines the efficiency of any given type. The efficiency being the ratio between the quantity of heat utilised in evaporation and that which would have been produced had the combustion been perfect.

The properties of coal will be dealt with later. A Table is subjoined giving the amount of heat necessary to raise 1 lb. of water from 32° Fahr. to $t°$ Fahr., and to transform it into dry steam at that temperature. (See Table on next page.)

The second factor determining the total evaporation of a boiler is the total quantity of coal that can be burnt. This depends mainly upon the area of grate and the air pressure.

24. *Various Considerations affecting the Efficiency of Boilers.*—Over and above the efficiency, the value of any particular type of boiler must be arrived at by taking into consideration the life of the boiler and its liability to accidents and breakdowns. The efficiency and safeness of any boiler depend upon its design, and the care exercised in its construction, and to a certain extent upon the care with which it is handled, and the proficiency of the stokers.

Total pressure in Pounds per Square Inch.	Temperature or boiling point in Degrees Fahrenheit t.	Δt.	Total heat required to generate 1 lb. of Steam from Water at 32° F. under constant pressure Q.	Δ Q.	Weight in lbs. of a cubic foot of Steam. δ.
1	102·0	..	1113·05	..	·003007
2	126·4	24·4	1120·49	7·44	·00578
3	141·6	15·2	1125·14	4·65	·008475
4	153·1	11·5	1128·63	3·49	·011097
5	162·3	9·2	1131·44	2·81	·01369
6	170·1	7·8	1133·82	2·38	·01626
7	176·9	6·8	1135·90	2·08	·01881
8	183·0	6·1	1137·75	1·85	·02135
[illegible]	188·4	5·4	1139·40	1·65	·02388
10	193·3	4·9	1140·89	1·49	·02641
11	197·8	4·5	1142·26	1·37	·02890
12	202·0	4·2	1143·55	1·29	·0314
13	205·9	3·9	1144·72	1·17	·03389
14	209·6	3·7	1145·87	1·15	·03636
14·7	212·0	2·4	1146·60	0·73	·03794
15	213·1	1·1	1146·93	0·33	·03867
20	228·0	14·9	1151·47	4·54	·05076
25	240·5	12·5	1155·29	3·82	·06262
30	250·5	10·0	1158·34	3·05	·07430
35	259·0	9·5	1160·95	2·61	·08576
40	267·0	8·0	1163·38	2·43	·09728
45	274·3	7·3	1165·60	2·22	·10845
50	281·0	6·7	1167·64	2·04	·1197
55	287·0	6·0	1169·49	1·85	·1308
60	292·6	5·6	1171·18	1·69	·14185
65	297·8	5·2	1172·76	1·58	·1528
70	302·8	5·0	1174·29	1·53	·16375
75	307·5	4·7	1175·74	1·45	·1746
80	312·1	4·6	1177·13	1·39	·18545
85	316·3	4·2	1178·41	1·28	·1962
90	320·3	4·0	1179·63	1·22	·2070
95	324·0	3·7	1180·77	1·14	·2177
100	327·7	3·7	1181·88	1·11	·2284
110	334·6	6·9	1183·99	2·11	·24985
120	341·1	6·5	1186·00	2·01	·27115
130	347·2	6·1	1187·85	1·85	·29236
140	352·[illegible]	5·7	1189·57	1·72	·3135
150	358·3	5·4	1191·22	1·65	·3346
160	363·4	5·1	1192·77	1·55	·3556
170	368·3	4·9	1194·27	1·50	·37635
180	373·0	4·7	1195·70	1·43	·3971
190	377·5	4·5	1197·07	1·37	·4176
200	381·8	4·3	1198·39	1·32	·4888
225	391·6	9·8	1201·39	3·00	·5396
250	400·8	9·2	1204·18	2·79	·5896
275	409·1	8·3	1206·72	2·54	·6388
300	417·1	8·0	1209·16	2·44	..

We shall, however, direct our attention more particularly to the construction of boilers, as it is difficult to lay down hard and fast rules for their management, except in regard to the old tubular boiler, where long experience renders this possible. These rules apply more or less to tubulous boilers, with the addition of some special precautions for the maintenance of the fires, supervision of the water-level, and management of the feed.

§ 2. FUEL AND GRATES.

25. *The Composition of Coal and its Analysis*.—Coal employed for firing boilers is composed mainly of two elements, carbon and hydrogen, associated with oxygen, nitrogen, sulphur, and certain mineral matters which constitute the ash. The sulphur is sometimes met with in appreciable quantities, generally in the form of pyrites.

One pound of hydrogen, when burnt, develops 62,030 British thermal units, or B.T.U., and requires for combustion 8 lbs. of oxygen.

Pure carbon (the result of the calcination of wood), when completely burnt and transformed into carbonic acid, develops 14,540 B.T.U. per pound, and in doing so consumes 5.89 pounds of oxygen. The calorific value of carbon, if very compact, diminishes slightly; it falls in the case of the diamond to 13,860 B.T.U.

Charcoal, when transformed into carbon monoxide by its combination with 1.33 pounds of oxygen, develops 4,450 B.T.U.

Carbon monoxide develops per pound of carbon 10,090 B.T.U., thus making up the 14,540 B.T.U. The difference of 5,640 B.T.U. between 10,090 and 4,450 is the latent heat of the carbon vapour.

The calorific value of coal is determined by means of a *calorimeter*. The latest form of this instrument is the

"bomb" calorimeter, devised by MM. Berthelot and Vieille, in which combustion takes place under pressure in pure oxygen. This is a very simple instrument, and can easily be used by engineers interested in the study of coal.

The analysing of coals, and the determination of their calorific value, has been undertaken by a large number of experimenters. The results obtained are mainly for English coals. Full information on these points will be found in the works of Messrs Stromeyer, and Seaton.

—	Calorific value per lb.	Results of Analysis.						
		C	H	O	S	N	Water.	Ash.
	B.T.U.							
Nixon Navigation, Glam. . . .	15,010	88·03	4·11	1·98	0·66	0·96	1·02	3·22
Tyldesley, Theperley & Co. . .	11,610	68·18	4·78	4·86	1·39	1·22	4·72	14·90
Tyldesley Coal Co.	12,730	74·46	5·10	8·25	0·49	1·53	6·07	4·09
Bickshaw Main .	13,430	78·93	4·90	7·24	1·04	1·56	4·36	1·96
Pemberton . .	13,040	72·41	5·16	8·84	0·93	1·41	6·70	4·55
Cramhawke . .	13,420	69·77	4·82	12·44	1·17	1·33	7·15	3·31
Wigan . . .	13,590	76·49	4·96	8·46	1·07	1·44	4·84	2·75
Welsh Ebbw Vale	16,221	87·78	5·15	0·39	1·02		3·66	
Welsh average .	14,858	83·87	4·79	4·15	1·43		5·89	
Newcastle average	14,820	82·12	5·31	5·69	1·24		5·12	
Lancashire average	13,918	77·90	5·32	9·53	1·44		6·18	
Patent Fuel: Warlichs . . .	16,495	90·02	5·56	..	1·62		..	
Coke: best Durham	12,832	85 to 92	..	..	0·25 to 2		4 to 12	
Petroleum . . .	21,244	84·7	13·1	2·2	0·00		0·00	

To these may be added the following figures of three French coals given by M. Scheurer-Kestner:—

—	Calorific value per lb.	C	H	O + S + N.
	B.T.U.			
Ronchamp.	16,440	89·09	5·09	5·82
Anzin	16,660	84·45	4·21	11·32
Anthracite.	17,020	88·03	4·11	3·6

The following results have been recently obtained by M. Malher under the auspices of the Société d'Encouragement.

	Volatile matter.	Calorific Value, per lb.	Analysis.					
			C	H	O	N	Water.	Ash.
	Per cent.	B.T.U.						
Commenting Gas Coal	37·4	14,166	80·18	5·25	7·19	0·98	3·00	3·40
Blanzy Flaming Coal	30·1	14,158	79·38	4·97	8·72	1·13	3·90	1·90
Leny Gas Coal	29·6	15,111	83·73	5·21	6·01	1·00	1·05	3·00
Saint Etienne Coal	19·8	16,185	84·55	4·77	4·59	0·84	1·25	4·00
d'Anzin Coal	13·7	15,107	88·47	4·14	3·16	1·18	1·35	1·70
Kébao Hard Coal	4·6	14,090	85·75	2·73	2·67	0·60	2·80	5·45
Pennsylvania	2·8	13,470	86·46	1·99	1·45	0·75	4·45	5·90

A number of attempts have been made to express algebraically the calorific value in terms of the results given by the elementary analysis, but they have so far not been successful. The oldest formula, that of Dulong, is simply—

$$(1) \qquad 14{,}540\,C + 62{,}040\left(H - \frac{O}{8}\right),$$

and neglects, amongst other things, the heat of dissociation.

In order to take this heat into account, it is necessary to know the exact composition of the coal, that is to say, a complete analysis of the elements entering into its composition.

M. Malher, after numerous experiments, has arrived at the following empirical formula :—

$$(2) \qquad Q = 14{,}652\,C + 62{,}100\,H - 5{,}400\,(O + N).$$

Giving the calorific value (a given weight of coal being taken as 100),

$$C + H + O + N = 100.$$

It is noticeable that, in the above expression, M. Malher obtains for the calorific value of Carbon and Hydrogen numbers which differ slightly from the generally adopted figures of Dulong.

The expression (2) can be written

(3) $$Q = 14{,}652 + 62{,}100 - 5{,}400\,(100 - C - H),$$

or on simplifying

(4) $$Q = 20{,}052\,C + 67{,}500\,H - 540{,}000.$$

The formula (2) is similar to (1), inasmuch as it only takes into account the chemical composition of the coal, and consequently can only give approximate results; the inaccuracy according to M. Mahler's table, being always less than 3 per cent.

26. *Gruner's Classification.—Qualities of Coal Specified for the French Navy.*—M. Gruner, in his treatise on Metallurgy, has given a classification of coals by using the length of the flame as the classifying agent; this classification follows the order of their densities, and most probably in the order of their geological formation from the lignite up to the anthracite coals. The following Table gives a *résumé* of their classification:—

	Residue of Coke.	Volatile Matter.	Specific Gravity.	Calorific Value.
	Per cent.	Per cent.		B.T.U.
Lignite	30 to 45	70 to 55	1·15 to 1·20	12,600 to 14,400
Coals. 1. Long flame .	50 „ 60	50 „ 40	1·25	14,760 „ 15,000
Coals. 2. Bituminous—long flame	60 „ 68	40 „ 32	1·28 „ 1·30	15,300 „ 15,840
Coals. 3. Bituminous—ordinary flame . .	68 „ 74	32 „ 26	1·30	15,840 „ 16,740
Coals. 4. Bituminous—short flame	74 „ 82	26 „ 18	1·30 „ 1·35	16,740 „ 17,280
Coals. 5. Hard — little removed from anthracite .	82 „ 90	18 „ 10	1·35 „ 1·40	17,100 „ 16,560
Anthracite . . .	90 „ 95	10 „ 5	1·40 & above	16,560 „ 16,200

Gruner's method of analysis consists in the slow distillation of the coal until completely calcined. The products of distillation consist of ammoniacal liquid, tar, and gases containing carbon in varying proportions.

The analysis of coal No. 1 and coal No. 5 gives a nearly constant value for hydrogen, varying irregularly between 5 and 4 per cent. The quantity of carbon only varies between 75 and 93 per cent. instead of between 50 and 90 per cent., and the quantity of oxygen and nitrogen combined drops from 20 to 3 per cent.

Coals Nos. 1 and 4, for various reasons, have the common characteristic of not caking when being converted into coke.

Coal No. 4 is specially adapted for burning in marine boilers. It is to this class that the English Cardiff coal and the French Anzin coal belong. The Pacahontas coal of the United States gives the following analysis:—

Coke	75·92
Volatile Matter . .	18·14
Sulphur	0·75
Ash, etc. . . .	5·19
	100·00

Coals containing 14 per cent. of volatile matter may be used for briquettes. This corresponds very closely to the Anzin coal largely used in the French Navy.

The 8 per cent. of pitch added as a cementing agent increases the proportion of the volatile substance by 4 per cent. The briquettes made of poor coals, with only 10 per cent. of volatile matter, break up very easily in the furnace and fall through the bars. When new supplies of coal have to be furnished for the French Navy, the minimum proportion of 73 per cent. of coke is insisted upon prior to their being submitted to their reception tests. The calorimetric values and the elementary analysis give approximately the value of the coal as a combustible for marine purposes. The analysis and classification given in Gruner's Table give very reliable results, but in order to be perfectly sure of its value the coal should be tried on board, under ordinary service conditions.

27. *Coal Reception Tests in Force in the French Navy.*—The instructions for testing, which are still in force, dating from the 25th January 1861, and 8th April 1864, were issued under M. Dupuy de Lôme. They were drawn up with the object of arriving at the best coal for the rectangular return-tube boilers which were exclusively used at that time.

The evaporative power of the coal is determined by measuring very exactly the quantity of water evaporated per pound when burning half a ton of coal in a standard boiler.

Note is taken of the rate of combustion, and a distinction is drawn between the quick-burning and slow-burning coals. This is determined by the quantity of coal burnt per square foot of grate per hour at natural draught. The desire to burn a large quantity of coal at natural draught led to the use of quick-burning coals occupying a position above No. 4 of Gruner's scale. This has lost its importance since the introduction of forced draught which permits of the use of even anthracite coals.

The third class of measurements taken refer to the quantity of ashes and clinker remaining after combustion, and the amount of soot deposited in the tubes. These measurements are important, as cleaning the fires and sweeping the tubes are in themselves a laborious operation and may strain the boiler, not to mention the loss of heat that they give rise to.

The amount of ash left after calcination is measured in a crucible; this test also gives the proportion of coke to the volatile constituents.

Lastly, the cohesion of the coal is measured in order to test its ability to stand manipulation on board without crumbling to dust. No alterations have been introduced into these tests for cohesion since their first introduction. The coal is placed in a cylindrical receptacle, which is given fifty turns in two minutes. It is then passed through a sieve, and the ratio of the coal remaining in the sieve to the total quantity under test is taken as the measure of its cohesion.

The early trials with the standard boiler gave somewhat unexpected results, the most important of which are given in M. Picart's report published in the *Mémorial du Génie Maritime* in 1867. This report showed that the mixture of Cardiff and Newcastle coal used on all the trials was inferior to the Anzin coal in regard to evaporative efficiency, quickness of burning, and cohesion. The supply of Cardiff coal was stopped, and the manufacture of briquettes from the North of France coal-beds was commenced and further developed.

For twenty years the tests have been carried out in the different dockyards on the old rectangular boiler with a pressure of 25 lbs. to the square inch, which is sufficient for all comparative tests, and a large amount of information has been collected on the various French coals. When pushing the fires to determine the quickness of burning of the coals 20.5 to 26.6 lbs. per square foot have been burnt. The water evaporated, which was as low as 6 lbs. per pound of coal for inferior coals, with good briquettes rose to 8.6 lbs.

The quantities of clinker, ashes, and soot varied largely, but a good result, though rarely attained, and one easily to be remembered, is 3 per cent. clinker, 3 per cent. ash, and 0.3 per cent. soot.

As the old rectangular boilers required renewing they were replaced by cylindrical boilers with a pressure of 114 lbs. per square inch.

This change has more value in arriving at a comparison between the two types of boilers than in comparing the various classes of coal.

The quantity of water evaporated by the new boilers, due to the better arrangement of tubes and furnace, is naturally slightly higher, and further, the total heat of steam at 114 lbs. per square inch is only 2.5 per cent. greater than that at 28 lbs. per square inch. Good briquettes now give an evaporation of 9.6 lbs. Besides the old trials, where the fires

were slightly pushed, slow combustion trials were also carried out, but the results were so nearly identical as not to warrant the extra expense entailed.

Forced draught trials have now been added, in which 30 lbs. were burnt per square foot of grate, and the evaporation dropped about 15 per cent., seldom exceeding 8 lbs. per pound of coal.

The accompanying Table gives the tests specified, which are usually exceeded. The evaporation given corresponds to a combustion of 20 lbs. per square foot per hour:—

Name of Fuel.		Water evaporated per lb. of Coal.	Cohesion.	Ash remaining in the Calorimeter.
		Lbs.		Per cent.
Anzin briquettes .	for torpedo-boats	8·6	0·58	3·25
	ordinary . . .	8·4	0·55	7
Bessèges briquettes	for torpedo-boats	8·6	0·53	3·25
	ordinary . . .	8·5	0·53	5

It is by repeated tests, carried out on the standard test boiler, that briquettes equal to the well-known Nixon's navigation coal have been obtained.

28. *Tests in Different Countries.—Reduction to "from and at* 212°."—Evaporation trials are now carried out with great exactness in most of the leading countries. They include tests for the dryness of the steam produced, analysis of funnel gases, and other usual data.

In order to arrive at any exact comparison, account must be taken of the temperature from which the water was evaporated; in France this is usually reduced by means of a simple calculation to 10° C. (50° Fahr.). The pressure and temperature of the steam must also be taken into account. This second correction, which amounts to 36 thermal units when the pressure rises from 30 to 170 lbs. per square inch,

only amounts to 16 thermal units when the pressure rises from 170 to 310 lbs. per square inch. The latter correction, therefore, is not of much importance when comparing boilers of very high pressure.

In England the correction to "from and at 212° Fahr." is always used to obviate the variations of temperature in the water and the steam. A pound of water evaporated from and at 212° Fahr. necessitates an expenditure of 966 B.T.U.

Taking a boiler which evaporates 9 lbs. of water from 50° Fahr. at a pressure of 284.4 lbs. per square inch, the correction will be as follows: To 284.4 lbs. must be added the atmospheric pressure, 14.7 lbs.; this gives the absolute pressure as 299.1 lbs. per square inch, and the corresponding temperature is 416.8° Fahr. Then the equivalent evaporation "from and at" is given by the expression—

$$9 \times \frac{1{,}114 - 0.7 \times 416.8 + (416.8 - 50)}{966} = 11.07 \text{ lbs.},$$

a result very different from the original 9 lbs. of water. The quantity—

$$\frac{1{,}114 - 0.7 \times 416.8 + (416.8 - 50)}{966}$$

is called the *factor of evaporation.*

In round figures this correction increases the figure for the evaporation in the ratio of 1 to 1.2.

Measuring the efficiency by means of the water evaporated is always inexact, as no account is taken of the dryness fraction of the steam. For this reason the consumption of coal per horse-power is the best basis of comparison.

29. *Description of Different Kinds of Grates.*—Coal is burnt on various descriptions of grates, which are nearly always composed of steel or wrought iron, or sometimes, with certain kinds of coal, of cast iron.

The type used in the French Navy (Fig. 22) has a

maximum length of 2 ft. $9\frac{1}{2}$ in., a thickness on top of 1 in., with $\frac{5}{8}$ in. air spaces.

The spacing of the bars is kept constant by means of distance pieces, a small amount of play being allowed for expansion. This form of grate is well adapted for burning Anzin coal with natural draught when the fire is about 6 ins. thick.

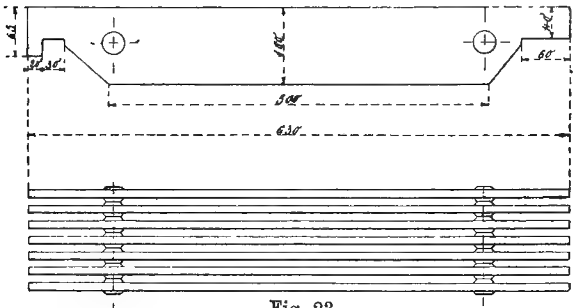


Fig 23.

Fig. 23A.

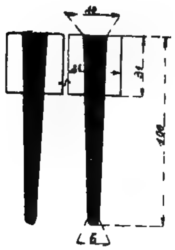


Fig. 22.

Fig. 24.

The English Admiralty uses thinner bars, about $\frac{3}{4}$ in. thick, spaced $\frac{1}{2}$ to $\frac{5}{8}$ in. apart, as shown in Figs. 23 and 23A.

In England the bars are sometimes riveted up together, two or three at a time, with distance pieces between them. This arrangement, which is also in use on several of the French torpedo-boats, makes the bars more rigid, and enables them to be made of greater length, up to, say, 4 ft. 3 ins. or 4 ft. 6 ins.

In America the upper surface of the bar is sometimes recessed (Fig. 24), and adds to the life of the bar.

Care is always taken to leave very little play between the side of the furnace and the bars, in order to avoid an influx of air and a consequent high temperature at this point.

For a long time a system of grate was employed on the Belleville boiler consisting of thin bars pressed into a special form and riveted up in pairs. This arrangement is shown in Fig. 25. The air enters through the hexagonal holes shown in Fig. 25A.

MM. Niclausse places the bars very close together, the air

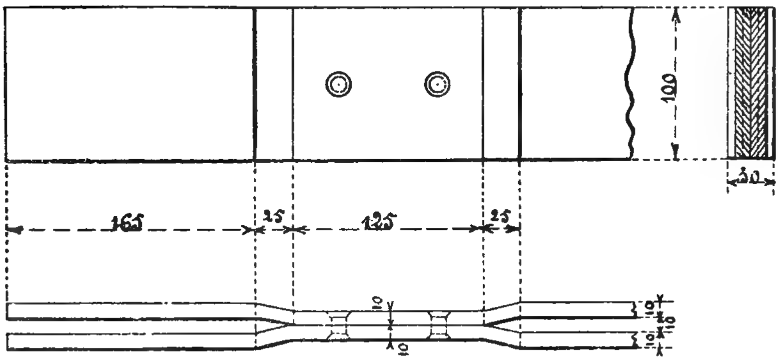


Fig. 25.

passages being only $\frac{1}{16}$ to $\frac{1}{8}$ in., the breadth of the bar being about $\frac{3}{8}$ in.

The ends of the fire-bars rest on bearers formed of two cross-bars riveted together with a space between them. At the fire-door end they rest on a broad cast-iron plate of sufficient breadth to prevent combustion taking place near the fire-door. The bearers and sole-plate are held in position by pieces of angle-bar riveted to the sides of the furnace.

In America various kinds of grates with movable bars have been used to facilitate stoking, having been adopted by the American Navy from locomotive practice.

The grate terminates at the back end in a bridge resting on a cast-iron or cast-steel cross-piece. The bridge keeps

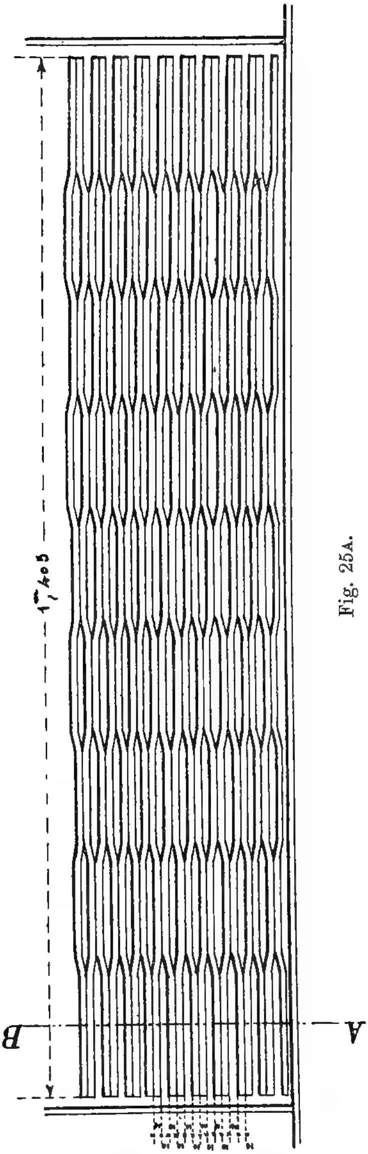


Fig. 25A.

Section on *AB*.

Fig. 25B.

the coal from falling off, causes the flame to rise, and closes the end of the ashpit. It is often provided with holes for the passage of air into the combustion-chamber.

§3. NATURAL DRAUGHT.

30. *Calculations for Determining the Draught.—The Velocity of Air corresponding thereto.*—The draught is due to the difference in weight between the hot column of air in the funnel, calculated above the grate, and the cooler column of air outside the boiler.

The depression existing in the boiler resultant from the difference above alluded to, and the velocity consequent upon the same, is usually measured, not in the furnace, but in the smoke-box. The instrument used in measuring this depression generally consists of a bent glass tube containing water, having one of its ends or legs in direct communication with the interior of the smoke-box where the depression exists, the other end being open to the atmosphere.

The draught thus measured is expressed in so many inches of water.

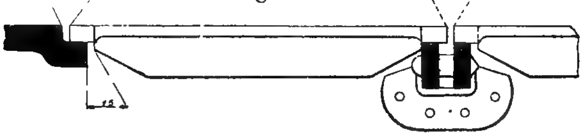
The column of air at a temperature of 572° has a specific weight of about half that of the external air.

If H be the height of the funnel above the bars, and the velocity be taken as uniform, the depression at the base of the funnel would be $\frac{1}{2}$ H. Expressing this in inches of water we have—

$$(5) \qquad h = \tfrac{1}{2} H \times \frac{0.0000466}{0.03611} \times 12 = 0.008 \, H.$$

Where H equals the height of the funnel in feet, and h the height of the water column in inches. The weight of

Fig. 26.



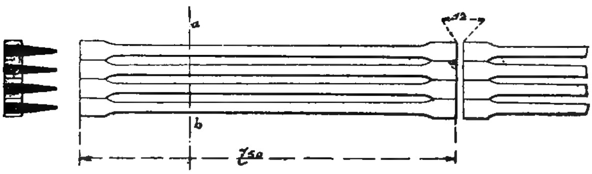


Fig. 26A.

1 cubic in. of air at 32° Fahr. is 0.0000466 lb., and that of 1 cubic in. of water 0.03611 lb.

Thus, at the base of a funnel 66 ft., 49 ft., or 33 ft. high the depression will amount to 0.53 in., 0.39 in., 0.26 in. of water respectively, on the supposition that the mean temperature of the gases in the funnel is 572° Fahr., and that the movement of the column of air is not obstructed.

Let us consider now the varying speeds of the different portions of the column of air on the assumption that it is unobstructed. Let V_1 and V_2 be the speed in feet of the

column of gases at two different points, at sensibly the same height, between which there is no resistance to motion, h_1 and h_2 the depression at these points expressed in inches of water, and δ_1 and δ_2 their respective specific weights in relation to the air.

The following relations will hold between V_1, V_2 and h_1, h_2 :—

$$(6) \qquad \delta_2 \frac{V_2^2}{2\,g} - \delta_1 \frac{V_1^2}{2\,g} = 108\,(h_2 - h_1)\,;$$

or, using Δ to denote a small difference—

$$\Delta \frac{\delta\, V^2}{2\,g} = 108\,\Delta\, h\,;$$

replacing g by 32, we get approximately—

$$\Delta\, \delta\, V^2 = 6{,}900\, \Delta\, h.$$

For hot air when $\delta = \frac{1}{2}$;

$$(7) \qquad \Delta\, V^2 = 13{,}800\, \Delta\, h\,;$$

for cold air when $\delta = 1$;

$$(8) \qquad \Delta\, V^2 = 6{,}900\, \Delta\, h.$$

If, for example, we consider the entrance of the cold air into the furnace without resistance, for a depression of 0.4 in. in the furnace, V = 52.5 ft. per second, and for a depression of 0.5 in., V = 58.7 ft. per second; these figures will only hold for the admission of air above the grate without resistance, and in such quantities that the value of h is not diminished. When the furnace doors are thrown full open the influx of air increases the resistance through the tubes, smoke-box, funnel, etc., and at the same time reduces the temperature. This largely diminishes the depression above the grate, and consequently the air does not enter the furnace at the speed above given by formula (8).

31. *Actual Speed of Gases.—Resistance due to the various parts of a Boiler.—Section of Passages required.*—Formula (8) does not even hold approximately, if we consider the air as entering through the ashpit doors.

It has been observed that the velocity of the air is 12.73 ft. on entering the ashpans for a depression of 0.52 in. in the ashpans, which corresponds to a depression of 0.43 in. in the furnace. If the air spaces between the furnace bars are equal to 60 per cent. of the grate surface, or say three times the section of the ashpit doors, the speed of the air through the bars will only be about 4.26 ft.

Calculating the depression for a speed of 12.73 ft., we have—

$$(9) \qquad \Delta h = \frac{12.73^2}{6900} = 0.023 \text{ in.},$$

a very small fraction of the whole draught.

At the base of the funnel the velocity of the gases is much greater than through the ashpans, on account of the reduced section, and also that the volume of the gases is increased, due to the increased temperature.

To the weight of the column of air must be added also the weight of the products of combustion.

Supposing the section of the funnel to be three-quarters of the section through the ashpits, the volume of the gas will be doubled when raised to 572°, and therefore the speed will be 2.66 times that through the ashpits. The increase of weight, amounting to about $\frac{1}{20}$, may be neglected. The value of Δh, therefore, at the base of the funnel may be taken to correspond to about—

$$0.023 \times 2.66^2 = 0.16.$$

The energy absorbed in putting the column of gases in motion is small compared with that absorbed in over-

coming the resistance of obstructions, of which thus far we have taken no account.

Neglecting the resistance due to the ashpits, which is not great, the draught of 0.51 in. may be divided up as follows in a return-tube boiler :—

	Inch.
Resistance due to the funnel, uptakes and smoke-box . . .	0·02
,, ,, tubes	0·11
,, ,, fire-box bridge, furnace	0·06
,, ,, fire of moderate thickness. . . .	0·30
,, ,, inertia of column of gases. . . .	0·02
Total . . .	0·51

In the above division the total draught of 0.51 in. is measured from the fire-bars, thus neglecting the height of the smoke-box, where the draught is usually measured. The actual readings on the gauge would be 0.02 in. in the ashpit, 0.33 in. in the furnace, 0.39 in. in the combustion-chamber at the back tube-plate, and 0.51 in. in the smoke-box.

As a matter of fact, the movement of the gases is by no means uniform, and is subjected to great fluctuations. The following Table is of interest when considering the movement of the gases as a whole :—

	Section.	Temperature.	Approximate Velocity.
		Degrees Fahr.	Feet per second
Ashpan doors	0·2	86	13·12
Air-passages through grate . .	0·40	...	...
,, ,, the coal . .	0·21 (assumed)	2,912	85·31
Area above bridge	0·21	2,190	65·62
Combustion-chamber	0·21	1,742	55·78
Entrance to tubes at back tube-plate	0·18	1,292	49·21
Exit to tubes at front tube-plate .	0·18	662	32·81
Funnel	0·15	572	36 09

The grate area in the above Table is taken as unity.

The following Table gives sections of air passages for other classes of boilers :—

	Dupuy-de-Lôme Direct-tube boiler.	Torpedo-boats 105–114. Locomotive boiler.	Horizontal Donkey boilers.	Bigot boiler.
	Sq. Ft.	Sq. Ft.	Sq. Ft.	Sq. Ft.
Ashpan doors	2·77	2·85	2·21	2·63
Air-passages through grate. . .	3·30	5·56	3·42	5·59
Area above bridge	2·54	3·98	1·93	4·24
Area through tubes	2·29	1·31	2·50	3·25
Smoke-box	3·19	3·75	5·23	5·03
Funnel	1·84	1·21	1·62	1·71
Grate surface for one boiler . .	50·16	27·99	7·10	2·42

In tubulous boilers the section for the gases is generally very large where the gases leave the grate. Baffles are often employed to reduce the section and increase the length of the course of the gases through the nest of tubes. Even with natural draught the gases sometimes reach the funnel too quickly. The bottom of the funnel, which, under these conditions, is at a temperature of about 932° Fahr., becomes a dull red, and greatly increases the draught; this gives rise to the entry of an excess of cold air, and thereby reduces the efficiency of combustion. In a boiler, where the gases have too short a course, too high a funnel may lead to bad combustion, but in general it is advisable to have a high funnel.

32. *Height of Funnel.*—For a long time the regulation height given to funnels was about 52½ ft., and the stokehold gratings, for the access of air to the furnaces, were about three times the area of the ashpits.

About twenty years ago it was first noticed that the draught was improved by increasing the height beyond that named above, more especially if the funnel casing was used for the ventilation of the ship. It was thus in employing a

double casing for the ship's ventilation that the expediency of increasing the height of the funnel of the old boilers was discovered.

In practice, the height of the funnel depends largely on the height of the upper deck and the class of vessel. On a cruiser, when the flying deck is about 33 ft. above the grates, the funnel may have a total height above these of 69 ft. On the *Columbia* and *Minneapolis* the funnels are 98.5 ft. high, though they only have a height of 20 ft. above the upper deck. On a gunboat, when the upper deck is only 10 ft. above the bars, a height of 40 to 50 ft. might seem excessive to any one not conversant with the exigencies of the case. On smaller craft, such as torpedo-boats, the funnel is never sufficient for the draught, and forced draught has always to be resorted to.

The use of protective decks, where all openings are reduced to a minimum, has so dimished the section allowed for the passage of air to the stokehold as to render combustion at natural draught incomplete whatever the height of the funnel.

§ 4. FORCED DRAUGHT.

33. *Early Applications of Forced Draught.*—For a long time only natural draught was known. The height of the funnels gave sufficient draught to ensure a combustion equal to that of an ordinary land boiler, and suited to the then requirements of the service.

The adoption of surface condensers prohibited the use of the only method of forced draught then known, namely, that used on locomotives; on smaller boats, however, this method was still employed to increase the draught.

The great utility of having some method whereby the intensity of the draught could be raised and a good combustion ensured at all times, had for a long time been

recognised. Trials were made at an early date in America, where the anthracite coal used necessitated a good draught. Stevens tried various systems, from 1830 to 1850, of induced and forced draught. In 1861 Isherwood fitted eighteen gun-boats with closed stokeholds.

In 1866 the wooden frigates sailing under the American flag had centrifugal fans blowing into the ashpans. In 1870 the Author proposed forcing air into the funnel in order to obtain a good draught, *i.e.*, to be able to burn easily up to 20 lbs. of coal per square foot of grate under unfavourable circumstances.

34. *The Bourdon - Thierry System.* — Among the older arrangements, that of Bourdon—which was considerably improved upon by Thierry—may be mentioned. It was tried in the French Navy in 1859, but had for its object rather the improvement of the efficiency of combustion than the creation of forced draught, properly so called. The arrangement consisted of a ring of steam jets placed above the fire-doors and blowing steam over the grate. The stirring of the flame with the mixture of air, and the gases resulting from the decomposition of the steam, rendered combustion nearly complete before the hot gases were cooled down by contact with the heating surfaces. M. Aurous modified this system by causing jets of steam, arranged as ejectors, to draw in a certain amount of air above the grate, thus ensuring similar advantages to those obtained by forced draught.

The Bourdon-Thierry system was used in France from 1860 to 1870, but was then abandoned in consequence of M. Joessel having experimentally demonstrated that upon return-tube boilers it diminished rather than increased the thermal efficiency, and consequently the evaporative power of the boiler.

The adoption of tubulous boilers in which the course of

the gases is generally short, gave rise to a new application of the Bourdon-Thierry apparatus. In the Belleville boilers, where, with a good natural draught, it was found difficult to burn from 20 to 22 lbs. per square foot of grate, with the aid of this apparatus 26 lbs. could easily be burnt. Jets of steam were forced in in two places simultaneously, in the funnel and above the grate. The need of economising fresh water in the tubulous boilers led to the introduction of air instead of steam.

SAVOIE.

BOURDON-THIERRY APPARATUS FOR FORCED DRAUGHT.

Front view.

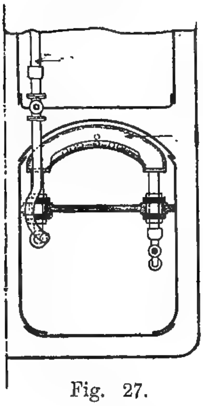


Fig. 27.

Longitudinal section through furnace.

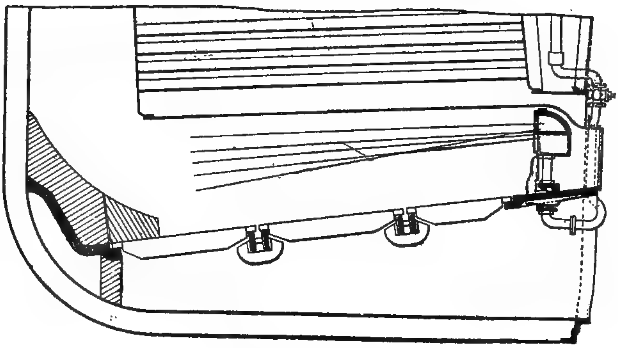


Fig. 27A.

35. *General Properties of Forced Draught.*—Forced draught is now becoming daily more general on account of two distinct and important results obtainable thereby, viz., firstly, that the boilers can be worked at their maximum evaporative capacity, sometimes, however, to their structural detriment, and secondly, that losses due to the funnel are reduced because, with forced draught, a larger proportion of the total heat contained in the gases is capable of extraction before they are discharged into the atmosphere.

The first trials made in the French Navy aimed at

increasing the power. The attempts to increase the economy of combustion are of much later date, and have been mainly followed up in the mercantile marine.

36. *Steam Jets in the Funnel.—M. Joessel's Trials.*—In 1869 and 1870 M. Joessel made some trials at Indret on steam jets in the funnel, concurrently with two other systems of forced draught, a fan in the funnel and the closed ashpit system. His results with the fans do not call for any special remarks, but the trials with the steam jets may be referred to with advantage.

M. Joessel's experiments were carried out on a boiler with 14.53 sq. ft. of grate surface and a working pressure of 32 lbs. per square inch. The steam for the jets was taken from an auxiliary boiler with the same working pressure as the main boiler. The results are given in the subjoined Table :—

Coal burnt per sq. ft. of grate.	Amount of Steam			Steam per lb. of Coal	
	Produced.	Expended on the Jets.	Available for the Engines.	Produced.	Available for the Engines
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
20·17	167·9	0·00	167·9	8·32	8·32
22·90	185·0	0·00	185·0	8·08	8·08
24·27	196·7	4·94	191·76	8·10	7·90
27·3	222·7	15·92	206·78	8·16	7·57
30·3	..	26·91	..	..	7·30
34·13	..	40·63	..	8·23	..
37·92	313·3	54·36	258·94	8·26	6·83
40·96	339·3	65·35	273·95	8·28	6·69

This Table shows that when using steam jets the combustion per square foot can be raised to 40 lbs.

Without steam jets, when burning 27.3 lbs. per square foot, the evaporation was only 200 lb. of steam instead of 222.7 lbs., thus showing that the forced draught improved the evaporative efficiency of the boiler. M. Joessel's experiments lead to the conclusion that improving the draught by means of steam jets in the funnel was to be the accepted

method of forced draught, but the advent of the tubulous boiler prevented its realisation.

Steam could not be taken from the main boilers, and although a donkey boiler for supplying the steam jets might easily have been used on board, it does not seem to have been applied practically, except in the case of the *Hirondelle*, where an increase of 22 per cent. in the power of the engines was realised.

37. *Steam Jets in Ashpits.* — *Niclausse Apparatus.*— M. Niclausse tried, in 1896, a system of steam jets in the ashpit. Two steam jets on the front of the boiler induce a current of air. The arrangement is shown in Fig. 28, and the results are tabulated below.

Grate surface, 11·62 sq. ft.; H.S., 561·3 sq. ft.; ratio, 1 to 48·3.

Length of trial . . hours	$4\frac{1}{3}$	5	4	5	5
Combustion per sq. ft. of grate—lbs.	20·5	25·6	30·7	35·8	41
Pressure of steam at jets—lbs. per sq. in.	28·4	56·8	95·3	106·7	120·9
Air-pressure in ashpits—inches of water	0·12	0·2	0·27	...	...
Air-pressure in uptake—inches of water	0·45	0·46	0·39	0·43	0·43
Temperature of gases at top of funnel . . . Fahr.	446°	482°	572°	662°	707°
Evaporation per lb. of coal .	8·5	8·7	8·6	8·48	8·25
Loss of fresh water due to jets—per cent.	3·3	4	4·5	5	5·2

The coal employed was the ordinary Anzin coal, and the boiler pressure was maintained at 206 lbs. in all the trials.

The quantity of steam used for the jets was determined, after the trials, by turning it into a bell-mouth coil sur-

rounded by water, and measuring the water condensed, conditions similar to those obtaining during the trials being maintained.

When burning 40.6 lbs. per square foot, the consumption of steam was practically identical with that given by M. Joessel.

A notable feature of the trials was the entire absence of clinker; only incombustible ash remaining. M. Niclausse carried out his experiments with a view of the possibility of applying this system to the navy. The experiments were not pushed further, and the system of blowing steam into

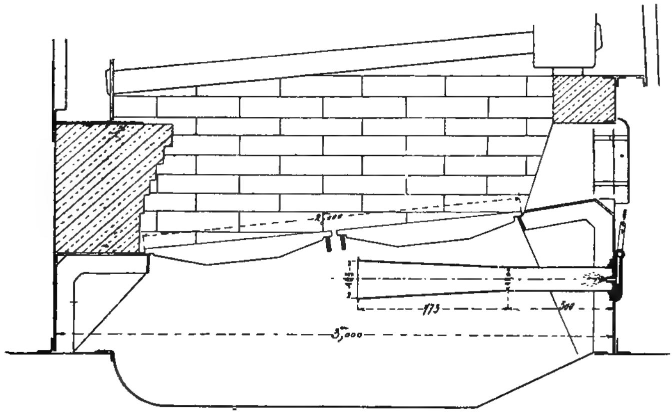


Fig. 28.

the ashpit has never found favour on board ship. On land, on the contrary, the system has been extensively used by Meldrum and others, and by its means poor and hard coals can be burnt with natural draught.

38. *Air Jets in Funnel.*—The first proposals to use air jets were negatived on the supposition that steam jets were much more economical. There is, however, no foundation for this supposition. Steam can, on account of its lower density, compress to its own pressure a quantity of air equal to about four times its own weight. There may also be an advantage

in adopting a pressure for the air jets differing from that of the steam, and therefore, for economic reasons, their use may be advantageous.

When higher pressures came into vogue and forbade the use of fresh water, an experiment was decided upon on the *Fulminant* in 1875, and a preliminary trial was carried out a year later on the *Résolue*.

The boilers of the *Résolue* were of the ordinary cylindrical type, with a working pressure of 57 lbs. per square inch. The air-compressors were simple condensing engines consuming about 33.5 lbs. of steam per horse-power. The jets fitted to the base of the funnel had a constant cross section of $\frac{1}{10}$ sq. in. per square foot of grate. The air-pressure rose with the working of the engines; it varied from 2.12 to 10.2 ins. of water.

The figures in the following Table, which are per square foot of grate per hour, have been calculated on the assumption that the blowers required 33.5 lbs. of steam per horse-power hour:—

Coal per Sq. Ft of Grate per Hour.	Required for Blowers.		Total Steam produced per Sq. Ft. of Grate.	Steam per lb. of Coal	
	Horse Power per Sq. Ft. of Grate.	Lbs. of Steam per H.P. per Sq. Ft. of Grate.		Produced.	Available.
				Lbs.	Lbs.
19·8	0	0·0	167·3	8·45	8·45
26·3	1	33·5	216·2	8·22	8·09
28·8	2	67·0	230·1	7·99	7·78
30·7	3	100·6	239·3	7·79	7·49
32·6	4	134·1	248·4	7·61	7·23
34·6	5	167·6	259·9	7·50	7·06
36·7	6	201·1	269·8	7·36	6·85
38·5	7	234·6	274·9	7·14	6·58
40·3	8	268·2	282·4	7·00	6·39

The efficiency of the boiler of the *Résolue* decreased steadily as the draught increased, while in the experiments at Indret the efficiency remained nearly constant. This difference can only be put down to the arrangement of the boilers, and

to inferior stoking. In order to compare air jets and steam jets as a means of increasing the draught, account must be taken of the amount of steam consumed at the same intensity of combustion. This gives 65.3 lbs. with steam as against 25.6 lbs. with air for a combustion of about 41 lbs. per square foot of grate, and therefore the steam jet requires 2.5 times as much steam to produce the same result.

The result obtained on the trials of the *Fulminant* in 1881, with a combustion of 27.57 lbs. of coal for 15.82 horse-power of the fans per square foot of grate, agrees with those obtained on the *Résolue*.

When comparing the effect of steam and air jets, the fact must not be lost sight of that the use of steam requires an expenditure of coal, which nearly doubles the consumption, in order to make good the loss of fresh water.

39. *Exhaust Fans in the Funnel.*—Until 1876 very little attention was paid to fitting the draught-producing apparatus in the funnel, which, from a working point of view, is a very convenient arrangement. On the *Sfax*, although the boilers were designed to consume 28.7 lbs. per square foot of grate, as a matter of fact, never more than 23.7 lbs. of coal were actually burned, and the use of air jets was abandoned. Owing to the success of Mr Thornycroft's first torpedo-boats, the system of forced draught with closed stokehold met with such a favourable reception that all other systems were for a time neglected. It was a long time before it was recognised that this system, at its most effective rate of working, is not suitable to large vessels with tubular boilers, and that if kept within the necessary limits, it ceases to compensate for the inconvenience attending its use. The tendency at the present time is to revert to open stokeholds; this is a return, after twenty years, to a less powerful but more convenient method, to which the name of induced draught has been given.

Air jets may possibly be again adopted, but in the meantime a fan placed at the base of the funnel, and drawing the gases through the smoke-box, is now frequently used. This arrangement, though formerly suggested by Stevens, was actually employed in 1876 on the *La Bourdonnais* by M. de Maupeou, who does not seem to have heard of Stevens' proposal.

M. de Maupeou tried a fan and jets of compressed air at the same time on board the *Biévre*; he compared the two systems by measuring the amount of work per square foot of grate required for each to give the same depression in the funnel. His results are given in the Table on page 76, from which it will be seen that the air jets consumed more power on the *Résolue* than on the *Biévre* to produce the same draught.

The trials of the *Biévre* show that a fan is more economical for pressure of 0.6 in. and over, but that the air jets have the advantage for pressures lower than 0.6 in. It is probable that the fan is markedly superior to the jets at all draughts when compressed air at high pressures, say of from 20 to 40 lbs. per square inch, is used, as has been lately resorted to in order to diminish the weight and space occupied by the compressors. Under these conditions, air jets have been found to be very costly on the *Léger*, the *Lévrier*, and on various vessels fitted with Belleville boilers.

By his experiments on the *La Bourdonnais*, M. de Maupeou established the inefficiency of fans in the funnel. Finally, he tried forcing the air into a closed stokehold, and found it more economical than the system of induced draught in the funnel.

40. *Closed Stokehold System of Forced Draught.—Application to Torpedo-boats.*—The closed stokehold system of forced draught consists in forcing air, by means of a fan, into a stokehold which has been closed, leaving the air no other

exit than through the grates, and thence to the uptake. Having already been tried in 1846 by Stevens, applied a little later by a Dutch river steamboat company, and adopted by Isherwood on his gunboats, this system was definitely introduced into the Navy by Thornycroft as a sequence to the introduction of the torpedo-boat.

In order to push the boilers of torpedo-boats, very much higher draughts have to be employed than on the *Résolue*, which never exceeded $\frac{3}{4}$ in. of water for a combustion of, at the most, 41 lbs. per square foot of grate. From the first Mr Thornycroft aimed at obtaining the same results as realised on locomotives, which burn 144, 164, and even 225 lbs. of coal per square foot of grate at a draught of 10 in. of water. Adopting a boiler of similar construction, he forced in air by means of a fan until the pressure rose to 7 and even 8 ins. It was apparent, however, that this was higher than was necessary. The closed stokehold system has not in any degree the valuable features of induced draught, as met with on locomotives, where the combined effect of the induced draught and the influence of the speed of the train on the supply of air to the ashpan varies directly with the speed on the engine itself, and regulates the rate of production of steam in direct proportion to its consumption.

The want of head-room in a torpedo-boat will not permit of the very high furnaces that are used on locomotives, or a thickness of fire in keeping with the powerful draughts employed. The very strong currents sweeping through a thin fire cooled down the gases and carried with them particles of burning coal instead of cinders. The more violent the current of air the larger was the total amount of coal put on; but the draught corresponding to the maximum evaporative power of the boiler was often exceeded. Little is known about the working of the fans at this period, but 1·83 I.H.P. of fan per square foot of grate would appear to have been reached and even exceeded.

The reaction against the overworking of torpedo-boat boilers has been slow in setting in. A combustion of 123 lbs. of coal per square foot of grate per hour on board the *Téméraire*, 130 on the *Défi*, and 154 on the *Alarme* has been obtained with a consumption equalling 4.7 lbs. of coal per indicated horse-power, which is very nearly the consumption of locomotive engines. The excessive consumption was one of the minor objections to the uneconomical working; the principal objections were the frequent failures while under steam, at the joints between the tubes and tube-plate, and the rapid wear resulting from fatigue of the whole boiler. Finally, the physical standard for stokers in the Navy does not furnish men capable of standing the frequent charging of the fires that is necessary with such a high rate of combustion. Moderation is, consequently, a necessity. Upon the fifteen 50-ton torpedo-boats fitted with the locomotive boiler, which were tried in 1890-91, the combustion did not exceed 72 lbs. of coal per square foot of grate per hour, though the air-pressure was still about 6 ins. Upon six of the above boats which were built by M. Normand, the maximum rate of combustion on the trials was between 53 and 63 lbs. per square foot of grate with, at the most, only 4 ins. of air-pressure. Under these conditions the consumption of coal per horse-power was not more than 2.23 lbs., and at times only 2 lbs.; the fan power was about 1.3 HP. per square foot of grate.

A consumption of 72 lbs. per square foot of grate per hour is the limit adopted on the new torpedo-boats fitted with tubulous boilers of the Du Temple or similar types. This rate of consumption is obtained, while keeping the fires thinner than formerly, with air-pressures below, or very little above 2 ins. of water. Now it is generally preferred to run with thicker fires, using from 3 to 4 ins. of water.

At Indret it is the practice to determine the allow-

able air-pressure h in relation to the combustion by the formula

(10) $$h = \cdot 00095\ C^2,$$

which gives 4.8 ins. for 71 lbs. The trials at Indret are usually on large vessels.

The following are results obtained from torpedo-boats :—

Name.	Speed.	Air pressure in inches. h.	Coal Burnt per sq. foot of Grate. C.	Coal per I.H.P. per Hour. c.
			lbs.	lbs.
Flibustier	at 14 knots	0·25	15·5	1·17
	at full speed	2·10	63·4	1·59
Ariel	at 14 knots	...	7·11	1·08
	at full speed	1·25	71·3	1·80
Torpedo-boat (No. 213)	at 14·17 knots	...	6·1	0·93
	at 27·86 knots	3·15	59·0	1·52
Forban	at 14 knots	...	7·06	0·86
	at full speed	4·75	63·9	1·36
Cyclone	at 14·25 knots	...	4·17	0·96
	at 30·38 knots	2·06	63·0	1·74
Durandal	at 14·25 knots	...	5·2	0·94
	at 27·41 knots	3·23	65·2	1·71
Fauconneau	at 14·25 knots	...	4·9	0.85
	at 27·14 knots	3·97	72·8	1·77

These figures show that the value given by the above rough formula, based on results of big vessels, are too high for torpedo-boats, except in the case of the *Forban*. Even at Indret the coefficient .00095 is often replaced by the figure .00075.

The coal per I.H.P. per hour averages in the above-named boats 0.97 lbs. at natural draught, and 1.67 lbs. with forced draught, an increase from 1 to 1.69, whereas the coal burnt per square foot of grate rises from 7.14 lbs. to 65 lbs., or an increase of 1 to 9.1.

41. *Closed Stokehold System of Forced Draught Applied to Large Ships.*—From the moment of its appearance on the first torpedo-boats, the success of the closed stokehold system of forced draught gave rise in France to a number of schemes for its general application; it was proposed by this means

to increase the power of existing boilers, and to reduce to about half the weights of the boilers in the boats then under construction. M. de Maupeou, who played a prominent part in the movement, examined carefully, as has already been seen, the comparative merits of the different systems put forward. He found that the closed stokehold showed a marked economy over the other systems, even when compared with a fan placed in the funnel. This is shown in the following Table, taken from his reports:—

Systems of Forced Draught.	Power of Fans per Square Foot of Grate for the following Air-pressures.			
	0·6 in.	0·78 in.	1 in.	1·18 in.
	I.H.P.	I.H.P.	I.H.P.	I.H.P.
Closed stokehold . . .	0·92	2·29	2·02	2·75
Air jets in the funnel .	1·28	3·21	5·13	7·34
Induced draught . .	1·83	2·93	3·67	5·23

As the result of these trials the closed stokehold system was definitely adopted upon the *La Bourdonnais* in 1876, and subsequently upon several other cruisers. The British Admiralty, however, did not adopt the system until 1882, when it was fitted on board the *Conqueror* and *Satellite*.

Those responsible for the designs of new boats at first accepted with caution the means of lightening the boilers which thus presented itself. As was stated above, the *Sfax*, which was intended to burn 29 lbs. per square foot of grate, only burnt 24 lbs.; while on the *Tage* the highest consumption obtained was 30 lbs. per square foot of grate. The system was applied to the old type of return-tube boiler, for which it was well fitted, being strongly constructed and well adapted to utilise the heat produced. The results of the trials were encouraging, the only objections being the complications introduced by the necessity of closing all the

outlets with double doors, and the uneasiness of the stokers at being shut up in the closed stokeholds.

Emboldened by the success of these trials, the constructors pushed the consumption up to 51 lbs. per square foot of grate. At the same time they abandoned the return-tube boiler in favour of the direct-tube type, which is more liable to failure, even at ordinary draught, and much less capable of sustaining such high rates of combustion. To this period belong the trials of the ironclads *Hoche*, *Marceau*, and *Magenta*, on which the consumption was equal to 50 lbs. of coal, the power required for the fans amounting to 0.27 H.P. per square foot of grate. Following these came the trials of the gunboats of the *Grenade* type, in which 51 lbs. of coal were burnt per square foot of grate, the fans requiring 0.24 H.P., and in particular the trials of the small cruisers of the *Forbin* type, upon which the combustion was pushed up to 66 lbs. at the cost of repeated accidents, bringing about the rapid destruction of the boilers.

The three cruisers, *Troude*, *Lalande*, and *Cosmao*, may be cited as examples of boats which gave, without any mishaps worth mentioning, successful results on their trials. The following are the data obtained from the trials, the horse-power required for the fans being calculated from their revolutions, which were 350, and the mean pressure on the pistons, which was equal to 57 lbs. :—

——	Horse-power of Fans per Sq. Ft. of Grate.	Pressure in the Stoke-hold above atmosphere.	Pressure in the Smoke-box below atmosphere.	Total Draught.	Combustion per Sq. Ft. of Grate.
		In. of Water.	In. of Water.	In. of Water.	Lbs.
Troude . .	·366	1·30	0·43	1·73	58·40
Lalande. .	·366	1·22	0·43	1·65	58·26
Cosmao . .	·366	1·02	0·49	1·51	52·70
Mean . .	·366	1·18	0·45	1·63	56·45

The gain in power and speed was as follows:—

—	Natural Draught.				Forced Draught.			
	F Horse-Power.	V Knots.	M	C Consumption per I.H.P.	F Horse-Power.	V Knots.	M	C Consumption per I.H.P.
				Lbs.				Lbs.
Troude .	3,439	17·56	8·156	1·97	6,351	20·91	7·933	2·85
Lalande .	3,666	17·31	7·867	1·90	6,447	20·69	7·783	2·92
Cosmao .	3,596	17·37	7·940	1·91	6,301	20·60	7·816	2·64
Mean .	3,567	17·41	7·987	1·92	6,366	20·73	7·844	2·80

It will be seen that for an increase in speed of a little less than one-fifth, the consumption of coal per horse-power increased one-half.

About the same time, in the trials of the *Yayéyama* in February, 1891, the speed was raised from 18.4 to 20.9 knots, and a still higher speed could have been obtained had not the fear of a breakdown prevented the fans from being run at full speed.

The closed stokehold system was very generally employed about this time by most naval Powers, until the results of actual working shattered the hopes based upon the early trials.

One serious inconvenience had already been brought to light by the trials, and this was the increase in the consumption of coal per horse-power in boilers unfitted for forced draught. An increase of 50 per cent. in the coal consumption rendered forced draught particularly unsuitable to ships of limited bunker capacity. Great disappointment was experienced in the behaviour of the boilers in actual practice. It was found that failures, principally leaky tube joints and the dropping of the furnace crowns, increased to an alarming extent. The dangers were by no means compensated for by the expected increase in power, as ordinary

stokers were incapable of realising it. The only salient feature that remained was the complication introduced into the service by the hermetic closing of the whole stokehold by means of air locks and double doors. It is not difficult to realise the bitterness with which the closed stokehold system was characterised as a "diabolical invention."

At the present day, by an extreme reaction, the use of excessive forced draught has been limited to torpedo-boats and destroyers, and the maximum combustion for battleships and cruisers has been fixed at about 30 lbs. per square foot of grate. The result of this is a loss of one knot in the estimated speed of the cruisers *Blake* and *Blenheim*, while in the French Navy, in order to maintain the same power for the estimated weight of the boilers, or the same weight for an estimated power, the extreme step was taken in 1892 of abandoning the use of tubular boilers before it had been definitely settled by what type of tubulous boiler they should be replaced.

The French Navy at the present day has in use a large number of tubulous boilers of limited or free circulation, which, on account of the arrangement of their furnaces and water-tubes, are not considered suitable for the employment of very high rates of forcing. Tubulous boilers of accelerated circulation, which are, on the contrary, capable of being energetically forced, were until the end of 1895 used almost exclusively in torpedo-boats. About this time the repeated successful results obtained on small boats seemed to warrant their trial on larger boats. Higher rates of forcing were then more generally accepted, but out of prudence only such rates as had been actually used on cylindrical boilers were first tried, *i.e.* 36 lbs. were obtained on the *Jeanne d'Arc;* 34 lbs. on the *Chateau-Renault;* 44 lbs. on the *Jurien-de-la-Gravière;* 46 lbs. on the *D'Estrées* and *Infernet.*

Far better results have been obtained, and that without in the least compromising the safety of the vessel, than were

originally laid down in the programme of December 1889. The boilers of the *Chateau-Renault* have not up to the present given rise to any anxiety when under forced draught.

			Infernet.		*D'Estrées.*	
			Natural Draught.	Forced Draught.	Natural Draught.	Forced Draught.
Number of furnaces lighted			[illegible]	8	4	8
Air-pressure in stokehold	*h*	ins.	...	1·38	...	1·68
Combustion per sq. ft. of grate	C	lbs.	10·8	41·3	13·3	45·2
Power developed . . .	F	I.HP.	2,095	8,510	1,847	8,652
Speed	V	knots	14·05	20·99	13·76	20·22
Coefficient of performance	M		8·46	7·84	8·77	7.48
Coal per I.HP. per hour	*c*	lbs.	1·5	1·88	1·42	2·0

A combustion of 48 lbs. to 50 lbs. may, from the experience gained with the *D'Estrées* and *Infernet*, be adopted without fear when using boilers of the du Temple or other similar type. Due to the favourable results they have given on the torpedo-boats, these boilers are much more in favour than they were in 1896. It is to be hoped that better results with forced draught will be obtained on large vessels than was the case previously.

The mercantile marine, which still remains faithful to the marine type of tubular boiler, has also taken up the subject of forced draught. The conditions of the problem are, however, considerably modified, as economy of fuel is sought for rather than lightness of boilers, and the complications of air locks, etc., arising from the use of the closed stokehold system of forced draught must be suppressed as far as possible.

42. *Closed Ashpit System of Forced Draught.*—The system of forced draught most generally employed in the merchant service is that of the closed ashpit, in which the fans, instead of forcing air into a closed stokehold, force it directly beneath the grates.

In this system, the pressure of the air in the interior of

the furnace being higher than it is in the stokehold, the fire-doors must be fitted in the passage leading the air from the fans, in order that a certain proportion of the air may be admitted through them above the grates. Moreover, in order to avoid the return of flame into the stoke-

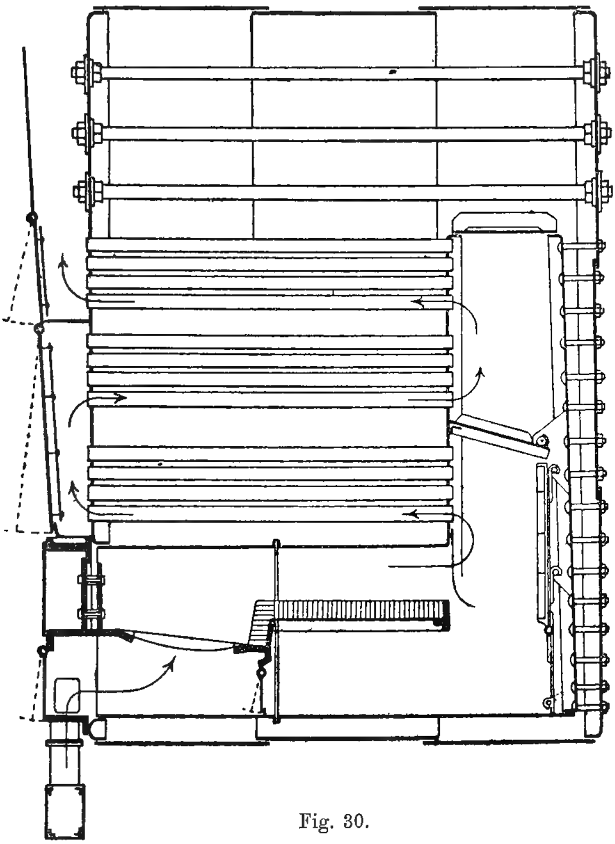


Fig. 30.

hold, the draught must be interrupted (which is usually effected automatically) each time a fire-door is opened. The air feed is also usually interrupted when the ashpit doors are opened, but this is merely to prevent an inconvenient escape of air into the stokehold.

The closed ashpit system has been applied on several

boats of the French Transatlantic Line. It was first applied by M. Audenet, as shown in Fig. 30, rather with a view of increasing the efficiency of the boiler than its power. The grate surface was reduced by one-half; the intensity of combustion was doubled by blowing in per pound of coal two-thirds of the quantity of air that would have been necessary with natural draught and the larger grate. All the after part of the furnace thus became a combustion-chamber. The gases were forced to pass through three sets of tubes by means of special horizontal diaphragms. The arrangement was tried on shore with success, but when fitted on board the coasting steamer *Mustapha*, practical difficulties were met with and the arrangement of forcing the gases three times through the boiler was abandoned.

M. Daymard, M. Audenet's successor, has used the closed ashpit system without reducing the grate area and without specially lengthening the course of the gases. He used, however, a special diameter of tube on some of the boats, and particularly on the *Touraine*. At first there was a good deal of trouble, due partly to the bad quality of the tubes and partly to the want of experience on the part of the *personnel*. The system has, however, been retained and gradually improved till great regularity of stoking has been obtained, and the life of the boilers does not seem to have been diminished. Similar installations on smaller coasting vessels gave better results from the very start, and these results have been maintained.

The ferry-boats on the Hudson use closed ashpits with great success. Only a moderate rate of forcing is employed sufficient to ensure complete combustion of the American anthracite coal. The closed ashpit system is nearly always used in conjunction with air-heaters, as in the Howden's system. This system was first introduced into France on the French Transatlantic boats.

§ 5. FORCED DRAUGHT AS A MEANS OF INCREASING THE HEAT EFFICIENCY.

43. *Forced Draught as a Means of Economising Heat.*—Natural draught, considered as a means of imparting to the column of gases the movement necessary to produce combustion, forms a very uneconomical motor. Supposing the gases to pass out at 522° Fahr. above the temperature of the air, the loss of heat is 2,400 B.T.U. per pound of coal, exclusive of the latent heat of the steam contained in the smoke; the only result obtained is a speed of 32.8 ft. per second imparted to a weight of gas composed of 19 lbs. of air to 1 lb. of coal—20 lbs. of gas in all; the energy per lb. of coal is given by the expression—

$$(11) \qquad \tfrac{1}{2} \times \frac{20}{32.2} \times 32.8^2 = 334.2 \text{ foot-pounds,}$$

that is to say, 0.00017 HP., an expenditure of heat corresponding to 0.15 lb. of coal per hour. The expenditure of heat per horse-power is therefore enormous. In other words, the mechanical efficiency of natural draught, regarded as a means of propulsion, is extremely small, practically *nil*, and all that can be otherwise used of the 18.9 per cent. of the total heat lost in producing natural draught is a net profit.

The heat of the gases can be made use of in four different ways:—

1. By increasing the length of passage through the water.
2. By superheating the steam produced, by means of an arrangement fitted to the boiler.
3. By heating the feed-water.
4. By heating the air necessary for combustion.

The water in the boilers, or the steam produced, cannot cool down the gases much below 570° through a metal plate,

since the temperature of steam at the pressures now in use is very nearly 400°. The various attempts made to superheat the steam have always failed, even when the temperature of the steam was only 250°, due, no doubt, to the bad conducting power of dry steam.

Audenet's arrangement for increasing the production of saturated steam by lengthening the course of the gases through the boiler has been abandoned. There remains, then, only the heating of the water and the air, which, in theory, would allow of the hot gases being cooled down to about the temperature of the surrounding air. The hot gases would be cooled down to the inlet temperature of the water or air, while the air or water would be raised to the initial temperature of the escaping gases. As regards the air, this might be feasible, but with the water it is not advisable to commence evaporation too early, as it might reverse the direction of circulation in the feed-heater.

44. *Feed-Water Heating.*—The weight of water evaporated in a well-constructed boiler is equal, in round numbers, to half the weight of the burnt gases, the specific heat of the water being nearly four times that of the gases. Neglecting radiation, the rise in temperature of the water in a feed-heater would be equal to half the decrease of temperature in the gases. This elementary reasoning shows that the heating of the feed-water provides a means of utilising all the heat that the gases can be deprived of, at the high pressures at present in use, which allow of a drop in temperature of 270° or more for heating the water. Theoretically, there is nothing to prevent the gases being cooled below 212° and thus condensing the steam.

Numerous attempts have been made to heat the feed-water by means of the escaping gases. Indeed, in some recent tubulous boilers, such as the Oriolle, Towne, Babcock and Wilcox, etc., a coil has been fitted for this purpose, and

forming an integral part of the boiler. The very first Belleville boiler had a feed-water heater, and the latest form of this boiler has a greatly improved apparatus of the same kind. Generally speaking, the heaters have been of small size, not very efficient, and have not necessitated the introduction of forced draught. As long as the temperature of the water keeps below boiling-point, and the heater is not subjected to internal pressure, it may be of very simple construction. There is a distinct saving in even a slight heating of the feed-water, and the efficiency of the boilers is increased by accelerating the formation of steam bubbles whereby the general circulation of the whole boiler is improved.

The heating of the feed-water by means of the escaping gases has been tried by Ebenezer Kemp, of Glasgow, who has given more attention to the subject than almost any other inventor.

In constructing several boilers for the Clan Line, from 1879 to 1886, Mr Kemp used small coils as feed-water heaters, having an area equal to one-tenth that of the heating surface of the boiler; the gases were only slightly cooled, and the natural draught, the only method employed by him, was not in any way affected. The consequent heating, as the temperature of the water was only raised 40° Fahr., hardly paid for the cost of the installation.

In 1886, on the *Bléville*, built for a Havre firm, Mr Kemp first made a serious attempt to solve the problem of thoroughly cooling the escaping gases. He fitted feed-water heaters, resembling small tubulous boilers, having a collective heating surface double that of the boilers themselves, and also an exhaust fan at the base of the funnel.

A trial was made in Glasgow Harbour, with the result that the escaping gases were cooled down from 1,040° to 356° = 684° Fahr., while the temperature of the water was

raised 360° – 120° = 240° Fahr. The hot gases were therefore taken at a very high temperature, and were discharged at a temperature 236° above that of the incoming water; 3,283 thermal units were abstracted from the gases per pound of coal consumed (20 × 684 × 0.24 = 3,283), of which 2,394, at the most, were absorbed, and 889 were lost by radiation or conduction in the heater.

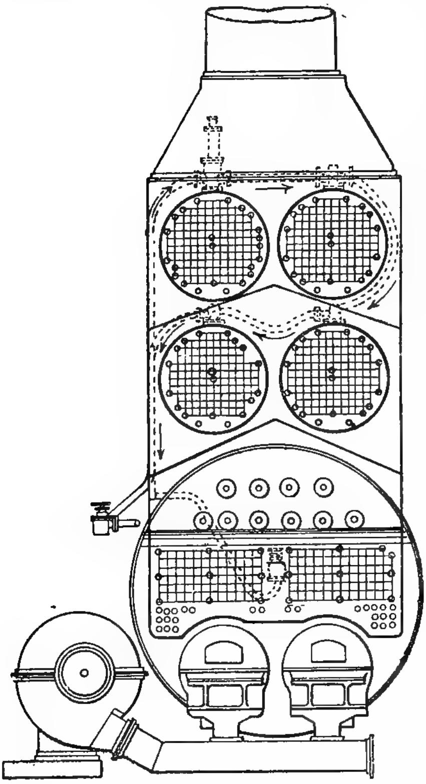


Fig. 31.

Trials with natural draught were made both in harbour and at sea.

In harbour it was found that 1.18 lbs. of coal per horse-power were consumed, being 14.9 lbs. per square foot of grate, a very good result for a triple-expansion engine working at 160 lbs. pressure. The hot gases had an initial temperature of 644°, which was reduced to 302° Fahr.

At sea, on a voyage from Glasgow to Havre, the consumption of coal was never below 1.41 lbs. per horse-power. The idea was, however, soon abandoned, as it was found that the heater tubes became perforated, and that, owing to the formation of steam chambers, gave out at the joints. The heaters were first taken out, and subsequently the boilers themselves, as without the heaters they were found not to be powerful enough; they were replaced by larger boilers weighing as much as the first and the feed-water heaters together.

Mr Kemp then adopted a new arrangement. In 1888, on the *Caloric*, forced draught on the closed ashpit system was used. The feed-water heaters consisted of four small cylindrical boilers, filled with water, and fitted with tubes for the gases to pass through. The gases, after passing through the lower group of heaters, returned through the upper one prior to reaching the funnel; they had an initial temperature of 680°, of which they lost 234° in the lower, and 207° in the upper group, finally emerging at a temperature of 239° Fahr. The water, on the other hand, circulated through the four heaters successively, gaining about 36° Fahr. in each.

It follows, therefore, that the hot gases lost 2,017 thermal units per lb. of coal, of which 1,440 were taken up by the water, and the balance, 677, was lost by radiation, the weight of water and gas being taken as before.

The heating surface in the *Caloric* heater is, relatively, rather greater than that on the *Bléville*, and the heating surface of the boiler itself is considerably greater; the principal data in the two apparatus and results of the harbour trials are given in the following Table:—

	Grate Area.	Heating Surface.		Ratio.		Cooling of the Gases.	Heating of the Water.
		Boilers.	Heaters.				
	G	S	S′	$\frac{S}{G}$	$\frac{S'}{S}$	ΔT	Δt
	Sq. Ft.	Sq. Ft.	Sq. Ft.				
Caloric .	38·47	1612·2	3498·3	42	2·17	441° F.	144° F.
Bléville .	70·72	1768·0	3390·7	25	1·92	396° F.	153° F.

The apparatus on board the *Caloric* had a practical trial while the vessel was doing between 38,000 and 40,000 miles a year; the hourly consumption per horse-power was 1.27 lbs.; the daily consumption was about 9 tons, while on the steamers of the same Line not provided with feed-water heaters, the consumption was about 11 tons, which gives a saving of

about 18 per cent. The working appears to have been satisfactory. At the commencement it was reported that some of the tubes showed signs of corrosion near the feed-water inlet, which was in no way surprising, as the water at that time was not purified in any way or neutralised by the admixture of alkaline substances, and that mineral oil was used for internal lubrication of the cylinders, and tallow for the stuffing-boxes. The corrosion of the heater tubes, however, saved those of the boiler proper.

The weight of the heaters on the *Caloric* cannot have been less than 57.4 lbs. per square foot of grate, or, say, about one-fifth of the total weight of the boilers.

Mr Kemp retired from practice in 1890, and died soon after. Since then the application of his principle appears to have been suspended, and the tendency is rather towards the use of steam for heating the feed-water. It would, nevertheless, appear as if a return were going to be made to heating water by means of hot gases.

The best known application of this is in the Belleville economisers described in Chapter XI. It is not merely a case of a small addition of an apparatus to the boiler but of a transformation of the boiler itself. The original heating surface of the boiler was reduced roughly by two-fifths, and additional surface S^1 was added, amounting to about two-thirds of the remaining heating surface. So that roughly the combined heating surfaces of boiler and economiser were about the same as the original boiler surface. The ratio S^1 to S in the Belleville economiser is about four times less than in the Kemp feed-heater, but, on the other hand, the temperature of the gases entering the heater is much higher. Feed-heaters were used on the Babcock & Wilcox boiler even before the Belleville boiler, and they are also fitted on the Montoupet boiler. On torpedo-boats with boilers of accelerated circulation, steam feed-water heaters as introduced by M. Normand, and described in Chapter XVIII., are

largely used in preference to waste gas feed-heaters. The steam used as the heating agent is taken from the receiver, or from the auxiliary exhaust after it has done useful work. But an economy is realised even if steam be taken direct from the boiler, as it increases the rate of circulation and the production of steam bulks at the lower end of the generating tubes.

Feed-water heating is particularly advantageous when using boilers with accelerated circulation. The practical difficulties attending the use of this system on board large ships has militated against its more general adoption. Weir's system of injection feed-heating, as it acts as a purifier of the feed-water at the same time, is being increasingly used.

45. *Howden's, and Ellis & Eaves' Forced Draught Systems.*—In the apparatus used for heating the air prior to combustion, very thin tubes are used, because they are not subject to any pressure. The cooling of the gases and the heating of the air must naturally be equal to one another, except for the losses in the heater. As there is no limit to the degree of temperature to which the air may be raised, so there is nothing in theory to prevent the complete cooling of the escaping gases. It would appear that water, owing to its high conductivity, is infinitely better adapted than air to abstract the heat from the gases, or in other words, that air would require a very much larger heating surface to do the same amount of work. This view is not, however, confirmed by practice. With apparatus having the same heating surface the temperature has been raised 180° with air, and 144° with water. At the same time, it is much more difficult to ascertain the temperature of heated gases subject to radiation than that of water.

The results of heating the air are somewhat complex

because the combustion of coal in hot air is much more rapid and complete than in cold air.*

It has been asserted, with some appearance of truth, that a rise of 180° Fahr. in the temperature of the air is followed by one of 360° Fahr. in that of the fire, owing to the more complete chemical combination; and further, by shortening the grate, all risk of cooling prior to its reaching the tubes is avoided.

Mr J. Howden has made a special study of the heating of the air for combustion. He began in 1859 by utilising the steam from the cylinders. In the process of condensing steam by cold water there is a much greater loss of heat than that which takes place by the funnel, and, up to the present, no remedy has been discovered for this evil. In 1860 Mr Howden took out a patent for a condenser in which air was used to cool the exhaust steam. This apparatus was not applied to marine engines: it might, perhaps, be worth a trial on locomotives on which water for condensing purposes cannot be carried.

Mr J. Howden turned his attention to heating the air for the furnace by cooling down the escaping gases. His apparatus was successfully applied on the *City of New York* in 1884, and the results were encouraging from the first. He estimated that the temperature of the air was raised to 184° Fahr. on this steamer; on the *Indiana*, another steamer of the American line, with a greater heating surface, the rise appears to have been 270°, while the temperature of the escaping gases was 455° Fahr. Under forced draught 22.03 HP. per square foot of grate was obtained. The *Illinois* and *Pennsylvania* have given similar results. Encouraged by these successes, the company fitted a similar arrangement on board the *St Louis* and the *St Paul*, Mr Howden under-

* The amount of heat produced by combustion, on the other hand, diminishes as the temperature increases; it becomes *nil* at a temperature great enough to dissociate the products of combustion.

taking with quadruple-expansion engines to give a consumption of 1.23 lbs. per I.H.P. per hour with 22 H.P. per square foot of grate.

In the United States Howden's system is now employed on all the vessels of the American Line, running on the Great Lakes, and, as will be seen later, on a number of warships.

During the past eight years the application of this system in England has undergone considerable extension, in spite of the adverse criticism encountered from those who, on principle, oppose forced draught rather than the hot-air system. The principal companies now using Howden's apparatus are:—the Cunard line, White Star line, Peninsular and Oriental, Royal Mail Steam Packet, British India Steam Navigation Co., Union Steamship Co. of New Zealand, Lamport and Holt line, Allan line, Clan line, Glen line, and the City line. Special mention should be made of the Star line of New Zealand, where Mr Silley, the company's engineer, has arranged an electric gear to indicate any excessive rise of air-pressure.

The Admiralty instructed the Boiler Commission to follow up the results obtained on the *Saxonia*, and in consequence the system is being tried on the cruisers *Antrim*, *Roxburgh*, and *Devonshire*, and also on the battleship *New Zealand*.

Howden's system is employed in Russia, on the Volunteer fleet, on steamers on the Don and on the Sea of Azoff, and also on the Ermach-Waidannah line; in Germany on the Hamburg-American line (in the *Deutschland*), and also on the Hamburg South American line; in Austria on the Austrian Lloyd and in Spain on the steamers running into Barcelona, Bilbao, etc.

In France it has been applied by the Transatlantic Co. on board their packet boats *Lorraine*, *Savoie*, *Eugène-Pereire*, *Duc-de-Bragance*, *Maréchal-Bugeaud*, and by several ship-

owners in Havre and Bordeaux, viz., M. Grosos, M. le Quellec, and MM. Maurel and Prom, on board their vessels.

The above incomplete list will give some idea of the importance of Howden's system. The large scale upon which it has been adopted may be gathered from the fact that the total number of vessels of all kinds fitted with this system amounted in 1905 to 1,800.

The arrangement when fitted to cylindrical boilers is shown in Figs. 32 and 32A, and differs very little from that used on the *Indiana* in 1895.

Forced draught with closed ashpits is now employed. Cold air is driven by a fan into the box A placed in front of the boiler; it passes through the smoke-box B, which has been suitably enlarged, where it circulates round a nest of vertical tubes, through the interior of which smoke passes; the air is made to pass evenly over all the tubes by means of the baffles *ee*, the latest improvement introduced into the system. The details of fittings, regulating the supply of air to the ashpits and furnaces, have been well worked out, and merit special attention.

The hot air is led to the different fires of a boiler by the large casing CC, fitted to the front of the boiler. In this casing the heating of the air is continued, and may ultimately attain a temperature of 400° Fahr. The casing C communicates with each closed ashpit D, by an opening fitted with dampers R, and with each furnace by a smaller opening fitted with a grid-iron valve S. The damper and grid-iron valve can be worked by hand, and regulate the supply of hot air above and below the grates. The dampers to the ashpit are closed during firing. The back plate of the fire-door is pierced with holes, and serves to distribute the air evenly over the furnace. The back end of the grate is slightly raised when a high rate of combustion, such as 60 lbs. per square foot of grate, is used. The whole arrangement is very simple, but

HOWDEN'S SYSTEM.

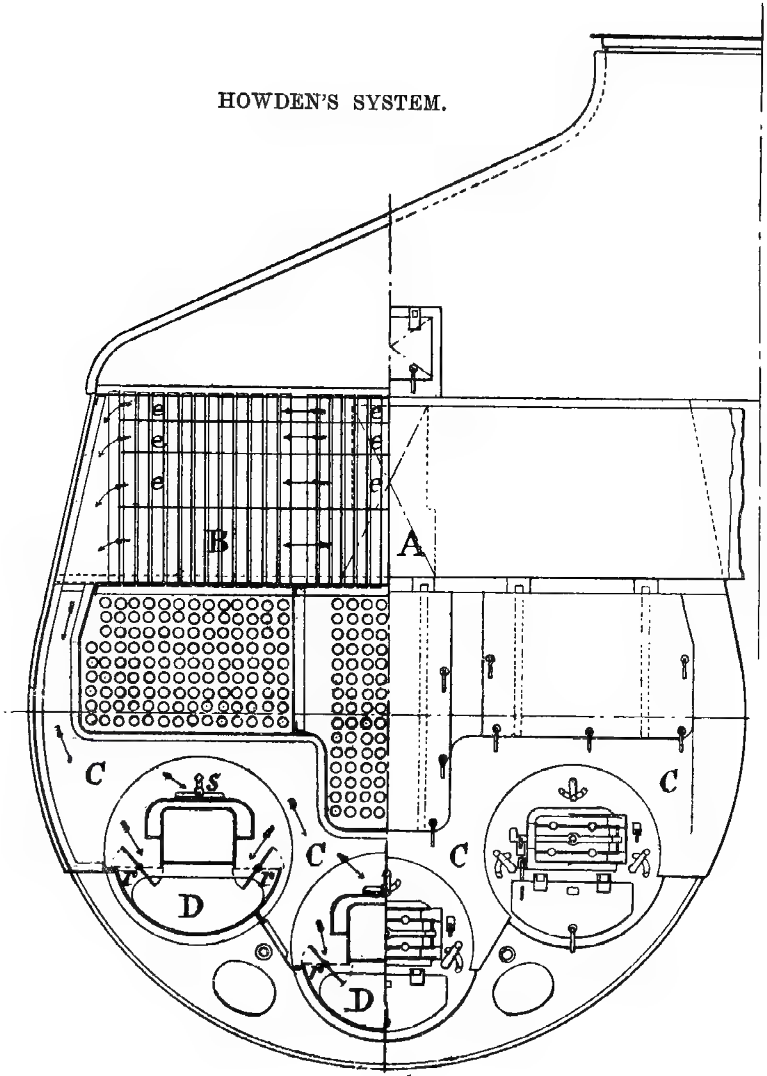


Fig. 32.

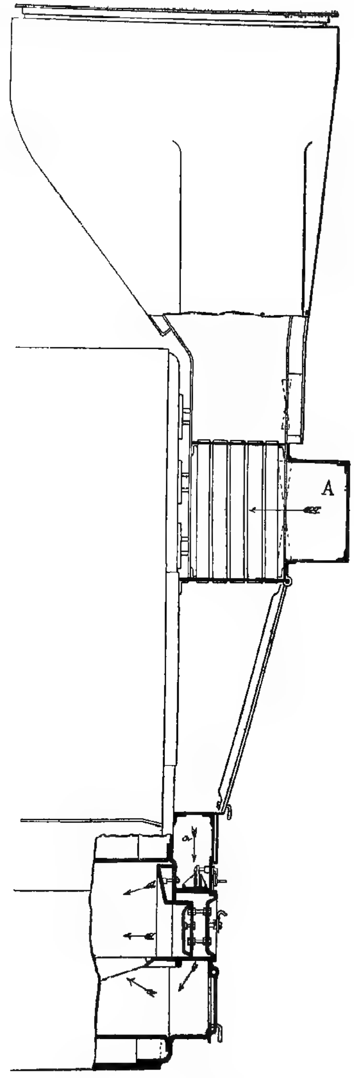


Fig. 32A.

[To face p. 92.

it is, nevertheless, advisable when contemplating the application of the system to new work to apply to Mr Howden direct for designs and particulars. The results of trials have shown that the adoption of the Howden system does not necessarily mean a saving of coal. The subject was discussed before the Institute of Marine Engineers, where a case was cited of a line of steamers, which had employed the Howden's system for a year on two of its boats that were running on exactly similar service to two other boats having only ordinary natural draught. The consumption on the boats fitted with the Howden's system was 1.72 lbs. per I.H.P., and on those with natural draught only 1.48 lbs. per I.H.P.

On the French Transatlantic boats it is said that an economy of from 6 to 8 per cent. has been obtained. The results must vary considerably as do the results of all consumption trials, depending as they do on the amount of draught and the regularity of the stoking.

By the use of forced draught, when the rate of combustion is doubled, the amount of air to be supplied can be reduced by one-third. The excessive loss of heat up the chimney is the only factor which affects the thermal efficiency. If Howden's system can ensure a lower funnel temperature, or at least an absence of rise of temperature, a certain amount of economy ought to be realised by the use of his system.

The great advantage of the Howden system is that it enables marine boilers to take advantage of their aptitude to stand forcing without injury. It enables a cylindrical boiler having a total weight about equal to that of a certain class of tubulous boilers, to produce as much steam with forced draught as these latter do under similar conditions.

The inventor has also tried the use of liquid fuel with this system. The fear of accidents which attends the use of forced draught, has for a long time prevented owners from adopting this system. A good deal of experience

has now been gained with this system; but there have, without doubt, been a good many cases of abnormal wear, of burning of fire-bars, of buckling of fire-tube plates, and of leaky tube joints. Careful and experienced firing is indispensable.

The fans cannot with impunity be set to give 3 ins. of air-pressure and the wheel of the stop-valve then removed, as has sometimes been done, because if the dampers to some of the furnaces are shut, the air-pressure in the remaining furnaces may go up as high as 6 ins., but, after all, the precautions which it is necessary to use to ensure the proper working of the system are not really excessive. An air-pressure of 3 ins., which appears to be about the pressure most generally used at the entrance to the air-heater A, is largely dissipated in the heater itself, and the actual air-pressure in the ashpit is quite moderate. The heating of the air to above 300° Fahr., which practically brings it up to the temperature of the boiler casing, does away with the danger of a rush of cold air into the boilers. The rate of combustion is wisely kept down in actual working, and on the line to Algiers 33 lbs. per square foot is never exceeded.

As it is convenient to be able to control the production of steam by the speed of the fans, more or less independently of the condition of the fires, general opinion appears to be that Howden's system ensures economy of combustion combined with comfort to the engine-room and stokehold staff. Thus, by the introduction of a simple system, a similar revolution has, without undue risk, been effected in the mercantile marine as was attained in the Navy in 1893 by the introduction of the water-tube boiler, burning up to 25 lbs. per square foot of grate.

The Howden System can be applied to water-tube boilers as well as to cylindrical boilers. It has already been adopted by the American and Dutch Navies. If it is to

be fitted on the type of water-tube boiler that is unable to stand a high rate of forcing, then the economy to be attained will be limited to a saving of coal. The system is especially adapted to those types of boilers which can stand as high or even a higher rate of forcing, than cylindrical boilers.

The best experience in this direction has been gained with Yarrow boilers in the *Noord-Brabant*, which made a run from Amsterdam to Botavia on a consumption of 2 lbs. per I.H.P. The *Friesland* with the same type of boilers, but without heaters, made the same run with most unsatisfactory results from a coal consumption point of view. When applying the Howden system to water-tube boilers, whose casings are seldom tight, the closed ashpit arrangement may, with advantage, be abandoned and the closed stokehold system reverted to, the air inlet into the boilers being arranged in close proximity to the fan discharge.

The heating of the air does not necessitate its being forced into a closed ashpit; it is quite easy to increase the intensity of the draught by using an exhaust-fan at the base of the funnel, which thus constitutes an induced draught on a closed ashpit system. This is practically the system brought out by Messrs Ellis & Eaves, of John Brown & Co., of Sheffield.

The Ellis system was first tried on the shop boilers at the works of Messrs John Brown & Co.; it was then adopted on the Shire line, in the *Perthshire*, *Buteshire*, and *Banffshire*, and on the *Berlin*, *Southwark*, and *Kensington*, The results being such that it has since been adopted in a large number of passenger liners and cargo boats, including among others the North German Lloyd Steamers, *Köningen Albert*, *Rhein*, *Main* and *Neckar*, the International Merchantile Marine Co.'s Steamers *Vaderland* and *Zeeland*, and the Hamburg-American liners *Hamburg* and *Nassovia*.

As originally arranged, the Ellis & Eaves air-heating apparatus comprised two separate horizontal tube boxes, one on each side of the boiler, connected on the front by the smoke-box, and having a common chamber at the back connected to the fan. The hot gases passed outside the tubes, having to take a somewhat complicated course round four right-angled bends, while the hot air for the fires passed through the tubes, having, on the contrary, a straight course.

It was found by experience that there were certain objectionable features in this arrangement, and some years ago improvements were introduced with the object of increasing the efficiency, reducing the weight, the first cost, and the space occupied, and the arangement as now fitted will be clearly understood on reference to Figs. 33 and 33A.

This modification of the earlier arrangement consists in the placing of a vertical tubular air-heater in front of the boilers, through which the waste gases are exhausted by the fan, the air of combustion passing on the outside of the tubes, diaphragm plates being so arranged that the whole of the surface comes into operation. The waste gases and the air of combustion have thus a practically direct course, and the drop in pressure is reduced to a minimun.

The air is heated to about 300° Fahr. and introduced into the fires through furnace fronts in which dampers are fitted so as to distribute the air over or under the grate in quantities varying with the quality of the fuel used.

One fan now suffices to supply two, or even three 16-ft. in diameter boilers. With a fan producing a vacuum equivalent to $2\frac{1}{2}$ ins. W. G. at the suction duct, it is possible to burn 30 lbs. per square foot of grate, and at this rate of burning to obtain 23 H.P. per square foot of grate.

The results obtained on a year's working of the *Kensington*, during which she crossed the Atlantic twenty times, the average I.H.P. per square foot of grate was 19,

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average I.H.P. per square foot of heating surface .596, the coal burned per square foot of grate being 29 lbs.

The *Inchkeith* fitted with cylindrical boilers having a steam pressure of 260 lbs., steam superheaters and the Ellis and Eaves system, on a twenty-four hours' test in the North Atlantic, developed 1,259 I.H.P. on a coal consumption of .98 lbs. per I.H.P., when burning at the rate of about 20 lbs. per square foot of grate.

The Ellis heater is fixed on the top of the boilers, and is divided into two parts, separated on the front by the smoke-box and at the back by the funnel; the hot gases which pass outside the tubes have therefore to take a somewhat complicated course round four right-angled bends. The distribution of the air in the ashpit and furnace is similar to Howden's, except that it can be controlled by separate dampers so as to give more or less air over or under the grate, according to the quality of coal used (Figs. 33 and 33A).

The advantages of the Ellis system lie in the general convenience of the suction process, to which may be added the avoidance of the injection of jets of very hot air into the stokehold. The pressure in the air and smoke passages being everywhere less than in the stokehold, the want of tightness in the joints is unobjectionable, indeed some holes are purposely left so as to create a draught in the stokehold. The furnace and ashpit doors may be opened without having to close any dampers, and by opening them the intensity of the combustion is increased, thus compensating for the cooler air admitted, therefore — so the inventors affirm — the cooling of the boiler, during firing, is very slight.*

* On this point stress might be laid on the results of a comparison which was made at Brest, on a Godard boiler, between the draught with closed stokehold and the closed ashpit system. With the latter, pressure dropped 15 lbs. on opening the doors; with the former there was no change. As regards the flow of air to the furnace, Ellis's induced draught has a similar effect to that of the closed stokehold.

The drawbacks to Ellis's system are those inherent to any system of induced draught, that is to say, a low fan efficiency due to working in hot gases of a low density, and in spite of the sudden cooling, of a less specific gravity than the surrounding air. The air to be heated has a tortuous passage round no less than nine right angles and drops 3.54 ins. in pressure before reaching the grate. While passing through the fire-grate another 0.35 in. is lost, and by the time the hot gases reach the fan they have lost a further 0.55 in. Messrs Ellis & Eaves obtain from the fan in their shop boilers a total pressure of 4.5 ins., while developing 0.3 HP. per square foot of grate. Marine boilers, it is true, with heaters more advantageously placed, require a smaller draught, viz.: 3.46 ins. on the *Berlin*, 2.91 ins. on the *Southwark*, and only 1.73 ins. on the *Perthshire*. The size of the fans is large, viz., 7 ft. 6 ins. on the *Berlin*, and 8 ft. on the Shire line. It is evident that it would be difficult to find room for fans of this size at the base of the funnels of ironclads.

The principal objection to this system is the difficulty of examining and maintaining the fans and their bearings, which are exposed to the high temperature of the funnel gases.

The Ellis & Eaves system has not been used on so large a scale as the Howden system, although on those boats on which it has been used it is generally well spoken of, both from the point of view of economy and ease of working. It has been fitted to about thirty-six cargo boats, of which about twenty-one are English, nine American and six German.

The *Perthshire* and the *Buteshire* have made several voyages to Australia, burning from 25.8 to 31.1 lbs. per square foot of grate (or a mean of 28.45 lbs.), while consuming 1.36 lbs. per horse-power of the main engines. If it be admitted that with the usual forced draught in closed

stokeholds, and without any heating of the air, it is necessary to burn 1.5 lbs. to obtain 21 HP. per square foot of grate, the saving effected in fuel by heating the air amounts to about 15 per cent.

On the *Berlin*, *Southwark*, and *Kensington*, the consumption per I.H.P. varies between 1.5 lbs. and 1.7 lbs. From evaporative tests, an evaporation of 11.74 lbs., from and at 212° Fahr., has been obtained.

Messrs Ellis & Eaves attribute a great part of the saving effected to the use of Serve tubes.

Neither Mr Howden nor Messrs Ellis & Eaves have given the weight of their respective heating apparatus. The author calculated that, in 1894, for a heating surface twenty-three times the grate area, it might be taken at 0.059 ton per square foot of grate on a boiler of the Du Temple Normand type, exclusive of the fans.

From the above it will be gathered that forced draught has been designed and applied in two totally different ways; the one on warships, where the object is to develop the greatest amount of power during a short time, the other on mail steamers, where it is most important to use as little fuel as possible during a long voyage. The different manner in which the two problems have been solved might at first sight appear to be in accordance with the circumstances surrounding each case. When, however, the question of weight, and also that of immunity from accidents—which is as important for warships as for the merchant service—has been thoroughly gone into, the solution arrived at is not so satisfactory as would appear at first sight.

Supposing that an air-heater, which utilises about 10 per cent. of the heat of combustion, reduces the consumption per I.H.P. by 10 per cent.; then it is evident, that, for a given amount of work, 10 per cent. will be gained on the area of the grates, with a corresponding saving of weight in the boilers when air-heaters are used. This saving

will more than compensate for the extra weight of the air-heaters as estimated above, should the boilers weigh more than 0.59 ton per square foot of grate, which is the general allowance in cylindrical boilers. In tubulous boilers, where the weight is always less than this, and where it may be as low as 0.32 ton, an increase of weight is unavoidable when air-heaters have to be adopted.

If in a boat in the mercantile marine the saving in the weight of fuel be taken into account, then a saving in the total weight will result. On warships, on the contrary, the use of air-heaters militates against running at slow speeds with ordinary draughts, which is the usual rate of steaming in service. If heaters are fitted, fewer boilers will be under steam, but they will always be more forced. It is this fact which makes the fitting of air-heaters to ships of war a doubtful economy.

§ 6. FIRING.

46. *Work of the Stokers.—Firing Tools.*—The main object of the stokers, and by no means an easy one to obtain, is to fire so as to maintain a uniform and constant thickness of coal on the grate, which should bear a direct proportion to the consumption per square foot. It is extremely difficult to maintain this uniform thickness, especially on long grates, and excessive inrushes of air will take place whereever the coal happens to be a little thinner. The fireman's motto should be "little and often." The relation between the thickness of the fire and the consumption per square foot of grate will regulate itself automatically, provided that the charges are put on in an equal and regular manner. The furnaces should be charged very quickly, as the currents of cold air have a most pernicious effect, both on the calorific efficiency of the furnace and the life of the boiler.

When stoking is properly conducted, all the furnaces should receive as nearly as possible equal charges at equal intervals of time; this is particularly necessary for the water-tube boilers of the Belleville, D'Allest, and Niclausse type, and the charges should be small and at frequent

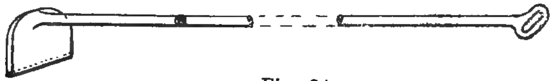


Fig. 34.

intervals. Thus, on the trials of the *Friant*, with Niclausse boilers burning 25 lbs. per square foot of grate, three or four spadefuls, weighing about 30 lbs., were put on the fire at about two-minute intervals, each grate having an area of 39.15 sq. ft. The better the stokers the thinner

Section on M N.

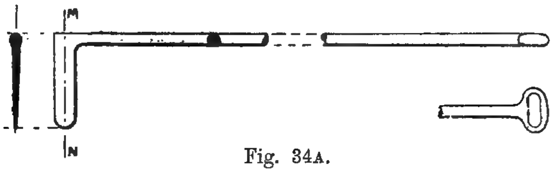


Fig. 34A.

the uniform thickness of fire they are able to maintain, and the more uniform the thickness the better the distribution of air in the furnace. The mean thickness should be from 4 to 6 ins., and increased as the intensity of the

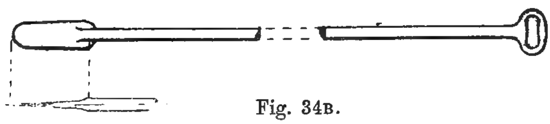


Fig. 34B.

forced draught increases, but very good stokers will not much exceed 4 ins. even at a high rate of stoking.

If the coal becomes caked at any part of the furnace, combustion at that point ceases almost entirely, the total combustion decreases, and repeated charging only tends further to block the grate. The shovel is the stoker's

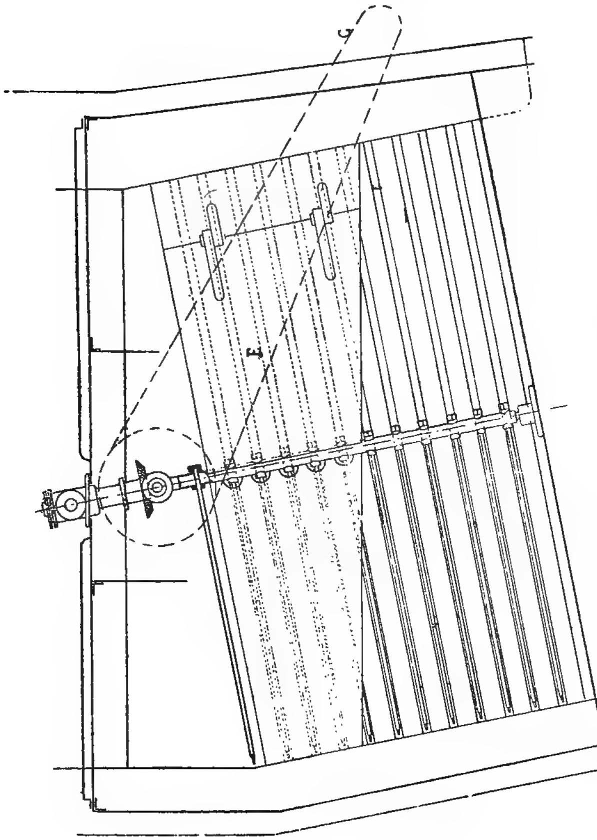
principal tool, and the ability with which an experienced stoker will handle it is remarkable, but is the result of a long apprenticeship. The other tools, such as rake, lance etc., used in cleaning the grates, need not here be dealt with.

47. *Cleaning the Grates.* — *Self-cleaning Fire-bars.* — The coal, when burnt, leaves behind it an incombustible residue, composed mainly of silicate of alumina and other alkaline silicates. The clinker collects on the bars, obstructing the air passages, and needs removing at regular intervals, varying according to the percentage of incombustible matter in the coal being burnt. Removing the clinker is a difficult operation and is generally performed about once in every eight hours. In trials for coal consumption, great care must be exercised in this operation.

Self-cleaning grates with movable bars have been used in America to get over this difficulty, and apparently with good results. In France, M. Moutte, Engineer-in-Chief at La Ciotat, has fitted, on the cargo boats of the Messagerie Maritime, self-cleaning grates, which after several years in service, have given satisfactory results. Iron bars of the usual pattern rest at either end on two separate dead-plates, each of which carries one half of the bars. The dead-plates are fixed at the two ends of an oscillating beam, the movements of which raise alternate bars, whilst the intermediate bars are lowered, and *vice versâ*. The beams being worked at the same time, the bars oscillate vertically and parallel to themselves.

The Moutte grates, owing to the relative movements of the bars, allow the cinders to fall freely. In order to get rid of the slag, it is necessary to let down the fires and allow the slag to cool off; but the cooling is less sudden and less complete than in the ordinary method of cleaning the fires, although the loss of coal is reduced. The economy

D'ALLEST TUBE-CLEANER.



A Steam to tube-cleaner.
B Handle to work movable screen.
C Chain for working tube cleaner.

Fig. 35A.

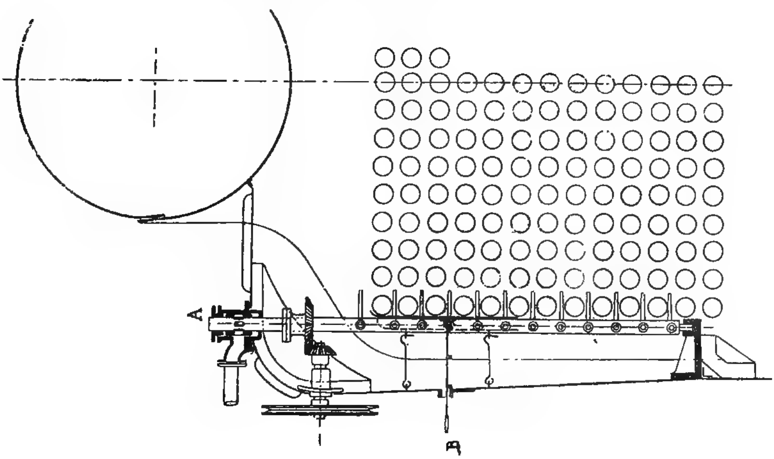
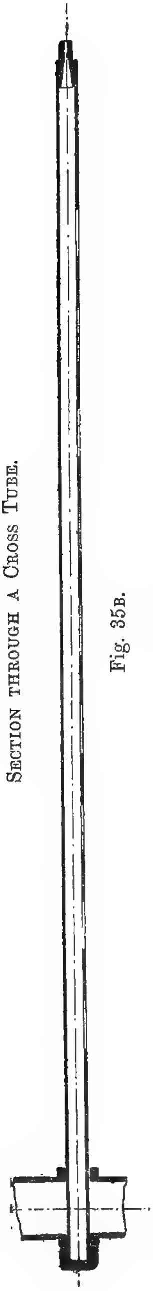


Fig. 35.

of fuel with the Moutte grate, on the results of a number of runs, appears to have been over 7 per cent. while the labour of the stokers was considerably reduced.

The Moutte grate is now being tried on board the *Latouche-Tréville*.



Section through a Cross Tube.

Fig. 35B.

48. *Tube Cleaning.* — Soot on the heating surface of the tubes is not less to be avoided than clinker on the grate. Twenty-four hours after starting, and then every twelve hours, the tubes ought to be cleaned. On cylindrical boilers a brush is passed down the tubes or a jet of steam sent through them; this operation is an easy, though a very disagreeable one on account of the heat, especially in the case of direct-tube boilers. On tubulous boilers steam cleaning is almost the only feasible plan, although it necessitates making up the fresh water expended.

The Belleville and Niclausse boilers are comparatively easy to clean on account of the arrangement of their tubes.

M. D'Allest has invented a tube-cleaner for his boiler which carries out the work very quickly. It is shown in Figs. 35, 35A, 35B. It consists of a single vertical tube with a large number of horizontal tubes branching off from it; these small tubes, by being rotated, pass between the boiler tubes somewhat in the form of a comb. A fine jet of steam escapes from the end of each tube, and also from a long, narrow slit down their sides (Fig. 35B), and by this means the cleaning is general and thorough. The D'Allest apparatus, which works well and

is not liable to accidents, should be used on all horizontal water-tube boilers. Unhappily the form of the tubes precludes its use on boilers of the Du Temple type.

On the Du Temple boilers, with curved tubes, the brush can only reach a certain portion of the tubes, and therefore, to clean them completely, recourse must be had to steam cleaning. The largest portion of the soot is carried towards the chimney, but a certain portion of it always falls on the lower drums, from whence its removal is a matter of some difficulty. This difficulty of cleaning the tubes is one of the most serious inconveniences inherent in this class of boiler. If the boilers are only under steam for a short length of time, then the tubes may be cleaned by a powerful current of air. This is effected by utilising the steam left in the boiler, after the fires have been drawn, to work the fans, closing up the stokehold and then quickly opening and shutting the fire and ashpan doors. This method, employed with great success by M. Chevalier, of Normand & Co., Havre, is a very strong proof of the solidity and endurance of the boilers of the Du Temple type. A similar operation would mean destruction to many other types of boiler.

At Indret, a trial has been made on the boilers of the *Jeanne d Arc*, of a steam tube-cleaner, the general arrangement of which is similar to that of the D'Allest tube-cleaner. It is a tube, having narrow longitudinal slits, and is introduced lengthways into the nest of tubes to be cleaned, and turned round so as to allow the steam jets to play upon the different tubes. This apparatus has given good results in the workshops, but it has yet to be tested in everyday working on board ship; but an apparatus fitted permanently in the centre of the nest of tubes is ultimately bound to get burnt.

The necessity of providing tubulous boilers with some safe, easy and effective method of tube-cleaning was

particularly emphasised on the first voyage of a Dutch cruiser, from Holland to India, when the coal consumption of the Yarrow type boilers was two or three times that which was anticipated, judging from the results of the consumption trials. Such a result can only be explained by an almost entire absence of any cleaning of the tubes during the trip. The new Belleville boilers fitted with economisers have not given in everyday work the results that were expected of them. This is doubtless due to the difficulty of keeping the economisers thoroughly cleaned. In several cases, the beneficial results attending the use of liquid fuel have been entirely vitiated by the rapid deposit of soot.

The only perfect solution of the problem consists in preventing any deposit of soot. From the results obtained with the Weir boiler, it will be seen that this desirable result can be obtained with tubulous boilers having accelerated circulation.

Some of the precautions necessary, when cleaning cylindrical boilers, are given in Section 95.

49. *Priming.*—Priming takes place by the juxtaposition of the bubbles of steam, which become connected on the surface of the water instead of bursting, and thus form a sort of emulsion, half liquid, half gaseous, filling the steam space and passing over to the cylinders. The old return-tube boilers, especially those working at a low pressure, were particularly liable to prime, although very steady in other ways. Priming is due to two causes—to an abundant production of steam, and to the viscosity of the water. A simple calculation shows that a cylindrical boiler, with three furnaces, evaporating five tons of water per hour, produces about 13,500,000 bubbles of steam of 0.078 in. diameter under a pressure of 170 lbs. per square inch. Under these conditions the bubbles can disengage themselves from the water fairly easily, but at a pressure of

57 lbs. the number of steam-bubbles produced was nearly treble the amount, and the slightest incident gave rise to tumultuous ebullition. The sudden opening of the stop-valves, or of the throttle-valve may often give rise to priming by occasioning a fall of pressure in the boiler, and consequently a greatly increased production of steam.

The best means of prevention are to give as large a surface as possible for the disengagement of the steam, and to raise the pressure, thereby reducing the volume of the steam.

Great care must be taken that nothing of a soapy nature finds its way into the feed water. The combination of fatty acids, arising from the lubrication of the cylinders, with the alkaline substances introduced into the feed-water, were for a long time a source of constant danger. Boilers whose interior surface had been coated with oil as a means of preservation needed carefully boiling out before being put into service. The introduction of mineral oils for lubrication of the cylinders and valves was a great step in advance. It enabled rates of evaporation to be realised on torpedo-boats, which, under other circumstances, would have emptied the boiler through the steam-pipe by excessive priming.

The absence of soapy matters is not alone sufficient, and certain sources of water-supply for this very reason must be avoided.

The good effects arising from the use of mineral oil led to the adoption of this substance as a preventive for priming, and sufficient quantity was introduced into the boiler to give a layer of about a sixteenth of an inch over the whole of the surface of the water, in order, so to speak, to filter the bubbles of steam and cause them to break and leave their water behind. Be this as it may, mineral oil in a boiler does not float for long, but sinks and forms a brown deposit which is a very bad transmitter of heat, and

dangerous to the heating surfaces, as has been noticed in Section 82.

When, in spite of all precautions, priming does take place, it is immediately noticeable by the disappearance of the water in the gauge-glasses and the shocks or hammering that follow in the cylinder. To avoid a breakdown in the engines, the speed is reduced and all the drain-cocks on the cylinders and piping opened. At the same time the fires are eased down by shutting the ashpan doors, and even sometimes by opening the smoke-box doors; but this last remedy is not to be recommended. Once priming has commenced it has a very pertinacious way of continuing, in spite of any reduction in the rate of working; but by suddenly shutting the main stop-valve the pressure is increased, which breaks up the bubbles of steam in the steam space and restores the water-level.

A sudden disappearance of the water-level ought never to give rise to anything in the form of a panic. After opening the feed checks to their full, one can easily afford to wait patiently for a few minutes. On a return-tube cylindrical boiler the furnace crowns may remain uncovered for nearly ten minutes if there is any rolling, or say five minutes if the vessel is steady, without fear of overheating. In a direct-tube boiler, where the crown of the fire-box is more exposed to the direct action of the flame, a critical temperature will be more quickly reached.

Given that there were sufficient water in the boiler before priming commenced, enough water will be left, even though it be in the form of an emulsion, to prevent the plates overheating. The engineer can safely reassure his strokers, and avoid, say for ten or fifteen minutes, drawing the fires, which should only be resorted to as a last extremity.

Amongst tubulous boilers, those with limited circulation, and those where the water-level is in the tubes, are especially exposed to heavy priming, should, owing to a fall of pressure,

the rate of evaporation be suddenly increased; thus, it is necessary to start the engines gradually when supplied with steam from Belleville boilers. Tubulous boilers with accelerated circulation are much less liable to priming, especially if the water-level is high in the steam drum.

50. *Accidental Disappearance of the Water-Level.—The Effect of Rolling.*—If the water-level disappears from the gauge-glasses without producing any shocks or knocking in the cylinders, and more particularly if the time of its disappearance is not accurately known, energetic measures may have to be taken, and the fires drawn. It should be borne in mind that the collapsing of the crowns of the combustion-chamber in tubular boilers may lead to very grave consequences for the *personnel*, and with tubulous boilers the overheating of the tubes, though not so serious for the stokers, is disastrous to the boiler itself. The accidents that have occurred on torpedo-boats are very instructive in this direction, and amongst them may be mentioned the collapsing of the crown of a locomotive boiler on board torpedo-boat No. 122, the complete destruction of the inner row of tubes on board the *Coureur*, fitted with Thornycroft boilers, and a similar accident on board the *Averne*, fitted with Du Temple boilers. The cause of the accident in each case was found to be shortness of water.

Sometimes it is not the shortness of water that gives rise to accidents, but the fact that the passages containing the hot gasses have been lifted above the normal water-level of the boiler, due to an alteration in the trim of the vessel. Excessive rolling may give rise to this difficulty, and it is a source of danger to which the engineer must be alive, more especially as some vessels heel considerably when the helm is put hard over; but moderate rolling or pitching which causes the water-level to oscillate may, on the contrary, be looked upon as a safeguard.

51. *Various kinds of Accidents.*—The form of accident to which a boiler is more particularly prone, and the means taken to prevent the same, vary with every type of boiler. It is sufficient to state here that, in cylindrical boilers, the furnace tube-plates and tube-joints are the most delicate portions, and the most exposed to serious accidents. Tubulous boilers are, on the whole, stronger, but they need handling with greater care, and the accidents to which they are exposed, though not so dangerous, are very numerous, and sometimes difficult to repair. Thus it is impossible to plug a tube while under steam.

Serious accidents are more likely to occur in the piping than in the actual boiler, and their gravity depends very largely upon the presence of mind of the stokers, since it is often impossible, for want of time, to examine the cause and give any orders. With a crew of experienced stokers, such as is usually met with on trial trips, there is every chance that the stop-valves will be shut down, should a rupture take place in the piping, before the stokehold becomes filled with steam.

If the leakage occurs in the boiler itself it may drive the gases back through the fire doors or ashpan doors, and soon render the stokehold unbearable. To overcome this, when running under the closed stokehold system, the air-pressure must be increased by increasing the speed of the fans, and at the same time the safety-valve should be eased. Fire-doors should be so arranged that, should a rise of pressure take place in the furnace, they cannot open of their own accord, and further, the ashpan door should always be made to close automatically.

In case of leakages, either in the boiler or in the piping, the only other general recommendations that may be advanced here are—to ease the safety-valves, to close the main stop-valves, and not to abandon the stokehold with heavy fires or an insufficient feed.

52. *Special Conditions of Firing on Trial Trips, and Length of Trials.*—On official trials, where the rate of cumbustion is as high as possible, and where the coal has to be burnt to the best advantage, the employment of very skilled stokers is necessary, and necessitates on the part of the engineers in charge a practical training, which can only be acquired by years of service. Objections have often been raised to these excessive full-power trials, but they are nevertheless necessary to prove what strain the machinery will stand, and in order to establish a comparison under similar conditions. The consumption trials, on the other hand, serve the purpose of determining the probable consumption when in service. In all consumption trials, whether at full speed or otherwise, the coal is measured and put into sacks, and the quantity put on the fire can thus be very accurately determined. The duration of the trial, which should cease at a time when the quantity of coal on the grate is precisely similar to that at the commencement of the trial, is somewhat difficult to determine with exactness; in fact it is impossible, even for a very experienced judge, to determine exactly the quantity of coal on a grate. On a grate with a thick fire no visible reduction in the thickness is perceptible in six to eight minutes, but, nevertheless, in a trial of four hours the amount consumed in this time must amount to three or four per cent. of the total consumption.

M. Joessel made use of the following method for determining the length of a consumption trial; the principle involved is sound enough, but its practical application is not without difficulty. To start with, all the furnaces are charged, which naturally gives rise to a fall in pressure, combustion is allowed to continue, and the pressure rises and remains stationary until such time as it again begins to fall, and this is taken as the commencement of the trial. Similar operations are carried out at the close of the trial. The position of the dampers not having been altered, it

is taken for granted that the moment when the pressure begins to fall in the two cases indicates a similar condition of grate. This hypothesis, however, does not take any account of blocking of the grates.

In one of the colleges in America another method has been advocated, which is sufficient for purposes of comparison. The fires are drawn at the beginning of the trial, and the grate is recharged with a given weight of coal and wood; the trial is then continued, and at the close the fires are again drawn and the contents of the furnace are weighed. The complexity of this method is sufficient to rule it out of court for all practical purposes. The most exact method of conducting accurate consumption trials seems to be to adopt a regular and methodical system of stoking prior to the commencement of the trial, charging the grates regularly at stated intervals, so that the fires may have thoroughly settled down prior to the commencement of the trial. The trial is stopped at an interval of time after the last charge, which corresponds exactly with the interval between the commencement of the trial and the charge immediately preceding it. By plotting the consumption in the form of a curve while the trial is in progress, it is easy to eliminate any irregularities which may have occurred at the beginning or the end, and to ensure that the rate of combustion corresponds closely to the mean combustion throughout the trial.

This system of methodical stoking at stated intervals, which was proposed thirty years ago by Rear-Admiral Labrousse and then abandoned, seems to be coming more and more into favour again, not only for consumption trials but also when it is desired to obtain the best results from the coal burnt.

53. *Experiments on Mechanical Stoking.* — Numerous attempts have been made to introduce mechanical stoking,

with the object of getting a more regular combustion than is possible even with the most methodical hand stoking, and to obviate the heavy work entailed upon the stokers. The most ingenious system amongst the many tried in the French Navy was that where the grate was composed of a number of endless chains known as the "Galle" system. Chains were placed close together and kept in movement, the coal was distributed evenly over the grate at the furnace door end, and arrived at the bridge completely burnt. The cleaning of the fires was also done automatically.

This system has been largely used for land boilers by Messrs Babcock & Wilcox, and others. On the marine type Babcock & Wilcox boiler a somewhat original system of mechanical stoking was tried in May and June of 1899 on board the *Pennsylvania*, a cargo boat of 10,000 tons, running on the Great Lakes. The following is a description of the system (Figs. 36 and 36A) taken from the *Engineer*.

The coal is contained in a hopper placed over a trough fitted with an Archimedian screw. In its passage from the hopper to the trough the coal is crushed between rows of teeth, and is then conveyed along the length of the furnace by the rotary movement of the screw. The projection of the blade or thread of this screw diminishes towards the rear of the furnace in order to reduce the rate at which the coal travels in proportion to that at which it is consumed and thus to maintain an approximately even thickness of fuel on the grate. A second trough is arranged around the one containing the screw, and into this air is blown by a fan. The air escapes through two series of openings, the one blowing over the coal issuing from the trough and the other upon the coke at the sides of the latter, and on the grates between them.

No air is blown into the ashpits, but only a small quantity of steam, viz., the exhaust from the engine driving the

stoker so as to prevent the adhesion of the clinker. This involves a small loss of fresh water, which, being on the lakes, is of no consequence. In case of accident to the mechanism, hand-firing may be resorted to upon the grates between the troughs.

Trials carried out under the superintendence of the American Naval Authorities are stated to have been satis-

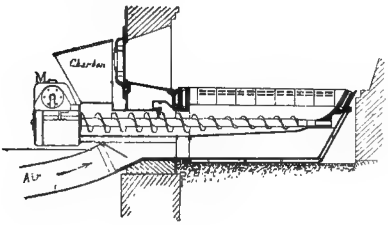


Fig. 36.

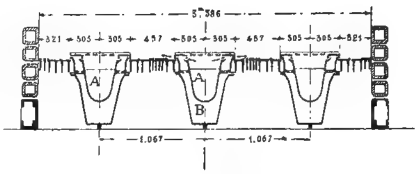


Fig. 36A.

factory in every respect, the stokers being easily operated and the combustion perfect. The application of the stoker has not, however, been extended, and the contrivance has yet to make its appearance on the high seas. It may further be supposed that in view of the revival of the old chain grate stoker, as fitted to the Babcock & Wilcox boilers in the Paris Exhibition of 1900, the arrangement used on the *Pennsylvania* has not since been adopted, even on board the cargo steamers of the Great Lakes. The fact still remains that the final result of all the trials of mechanical stokers on board ship has been, in the end, a reversion to the old methods of hand-firing.

Perhaps the solution of the problem of automatic stoking will be found in the use of dust-fuel, *i.e.*, coal reduced to such minute particles (dust-fuel) as to form with the air an explosive mixture. The jets of this fuel can be regulated and distributed in the furnace as easily as those of liquid fuel. This method has not yet been tried afloat, although a proved success on land. The Wegener system has been largely

adopted in Belgium, in Germany, and in some French works, as, for instance, in those of Messrs Bariquand & Marre, Paris. A marked economy of fuel is the main advantage obtained on shore by the use of this system.

The application of powdered coal firing to marine work presents some real and serious difficulties, mainly for the want of room for the feeders and grinding plant.

There have been several systems of firing by pulverised coal, but as far as England is concerned, only two, the Schwartzkopff and Cyclone systems, have been used on anything approaching a commercial scale. The chief difficulties to be overcome have been the grinding and the moisture contained in the coal. In all cases it is necessary to grind the coal so that at least 80 per cent. of it will pass a sieve having 8,100 holes per square inch. If the moisture before grinding exceeds 14 per cent. the coal will most likely clog in the mill, and the coal must therefore be dried previous to grinding, entailing extra cost and plant. Apart from this difficulty, the arrangement should, theoretically speaking, prove one of the most perfect systems of automatic stokering. Its application, however, entails alterations to the boiler, sometimes of an expensive though not prohibitive character.

The Schwartzkopff system consists of a hopper containing the powdered coal above the furnace, one side of which consists of a vibrating plate. Below this is a revolving wire brush and hammer head, which latter strikes against the vibrating plate as the brush revolves, and thus causes some powder to fall on the brush, which projects it into the furnace together with a small quantity of air. The bulk of the air is admitted independently of this, and is drawn in by natural draught. The furnace has all the ordinary bars, dead plates, etc., removed, and in place of these is lined entirely with fire-brick and provided with a fire-brick bridge. The coal burns with a white flame, and

CYCLONE SYSTEM OF BURNING POWDERED FUEL.

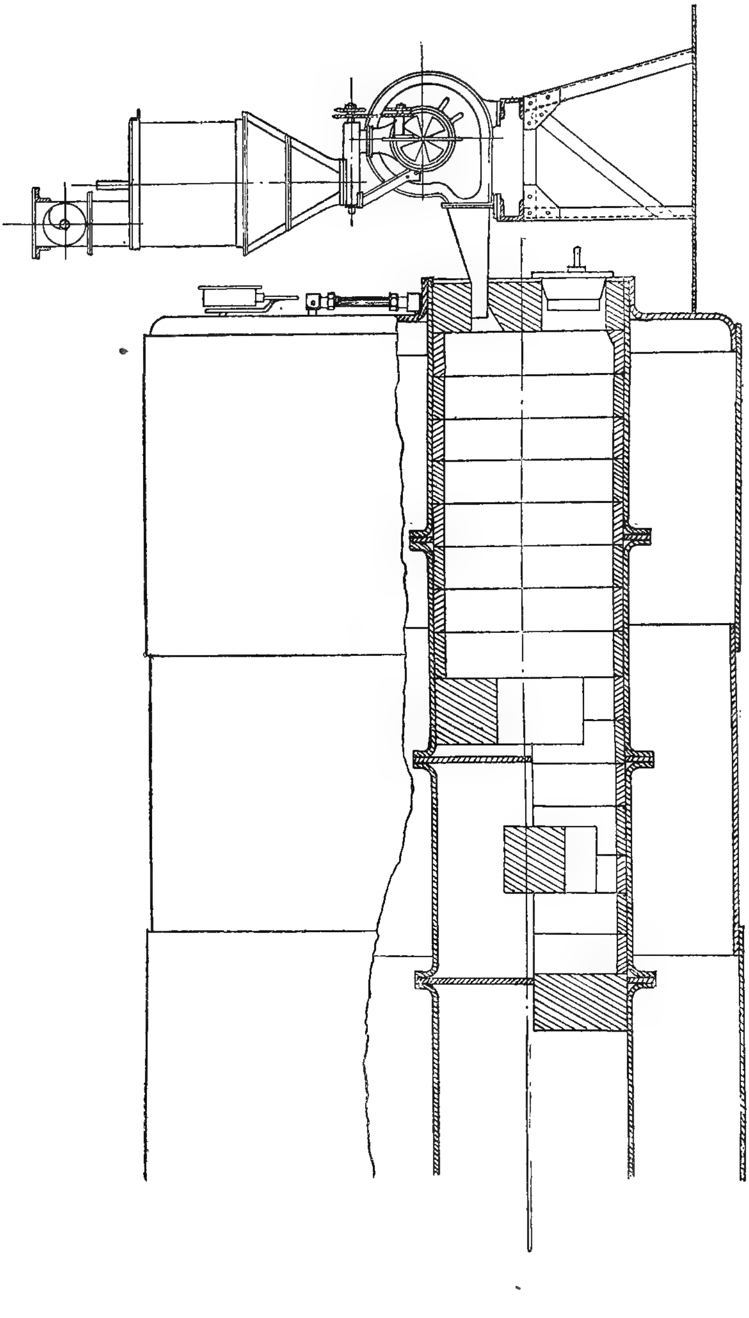


Fig. 37.

the ash is mostly deposited in the flues, from whence it can be periodically removed.

In the Cyclone system the front of the furnace is completely closed in. The furnace is lined with fire-brick and provided with baffles and a bridge, as shown in Fig. 37. The feeder consists of a fan having a hopper above containing the the powder which drops into a worm and is discharged by it at a regular rate into the inlet of the fan. The supply of air is regulated by means of discs over the inlet. The fan mixes the coal and air, and discharges them through a flat nozzle into the furnace. The worm is worked by means of gearing off the fan spindle, so that a reduction in speed of fan means a corresponding reduction in the coal supplied. Two or three gears are provided so as to enable the rate of feed to be varied, while the speed of the fan remains constant. Both air and coal are thus independently under complete control. Sight-tubes are provided to ascertain whether the fire is burning properly. The powdered coal and air become thoroughly heated on entering the furnace, and the heat causes the volatile gases to be given off immediately, and to ignite at a high temperature. The heat thus produced raises the temperature of the remaining air and carbon, and, as the solid carbon takes longer to burn than the gaseous hydro-carbons, complete combustion is not effected immediately, but continues during the progress of the gases through the furnace and tubes. For this reason a certain amount of the ash is carried on and deposited in the flues as an infinitely fine and soft white dust.

As combustion is nearly perfect, and that with a very small excess of air, a good evaporation and high efficiency is the result. Neither Welsh nor Anthracite coal can be easily used, but coal containing as low as 8 per cent. of volatile gases, and even coke dust, has been satisfactorily burned with an efficiency of 80 per cent.

Coal powder with 5 per cent. of moisture can be used,

but certainly no more. The cost of grinding coal is given by the makers as about 8½d. per ton.

One of the minor advantages of the Cyclone system of feeding is, that if the draught is bad the fans force the draught, whereas if the draught is good, they simply act as mixers.

Another advantage of powdered coal is the almost entire absence of smoke, as all the volatile matter, or smoke producing elements, are completely burnt. A cheaper class of coal can also be used. The longer the heating flues of the boiler the better, as the greater the time allowed before the gases touch the cold tubes or plates the better, otherwise some carbon may be condensed and form a coke deposit. This in horizontal smoke tubes is a disadvantage, especially if the tubes are close to the furnace.

On a Lancashire boiler fitted with economiser, 87 per cent. efficiency has been obtained. On a 14-foot economic or dryback marine 80 per cent. has been obtained, which might probably have risen to an efficiency of about 90 per cent. had an economiser been fitted.

The following Table gives a few results obtained with powdered coal firing:—

Boiler	30′ × 8′ Lancashire with Economiser.	30′ × 8′ Lancashire with Economiser.	15′ × 7′ Return Tube.	14′ × 11′ Dry Back Marine.
Total heating surface . . . sq. ft.	1,830	1,830	686	1,500
Coal burnt per hour . . lbs.	708	674	193	838
Water evaporated per hour . . lbs.	5,947	5,636	1,833	7,460
Water evaporated per lb. of coal . lbs.	8.4	8.35	9.5	8.9
Water evaporated from and at 212° Fahr. . . lbs.	10.08	10.01	10.1	10.8
Steam pressure . . . lbs. sq. in.	100	130	66	165
Feed-water temperature . ° Fahr.	57	65	180	112
Temperature of waste gases . ° Fahr.	313	239	360	555
CO_2 Vol. per cent., at end of combustion-chamber .. .	15.1	16.8	..	15.6
B.T.U. in coal, as fired . .	12,728	12,106	12,564	12,094
Thermal efficiency per cent. . .	76.5	80.5	77.6	80.5

To start the fires lighted oily waste is put inside the furnace, and the coal then admitted. The coal ignites at once, and in five minutes the full fire is on. It can be stopped instantaneously, but unless air is allowed to pass through the furnace, the heat absorbed in the brickwork will be given off and steam still generated. This is useful for retaining steam when banked for the night.

There is practically no danger from explosion, or spontaneous combustion when using coal in the powdered form any more than exists with ordinary coal dust. It is only explosive if mixed with the necessary air and heated to over 150° Fahr., when the volatile gases begin to be given off. The same care and precautions must, however, be used as with gas firing.

Powdered coal does not deteriorate to any extent in thermal value in consequence of being ground into a fine state. When kept for one year the loss in B.T.U. was just over $1\frac{1}{2}$ per cent., due to a loss of 8.6 per cent. in volatile combustible.

There would be little difficulty in the adoption of this system afloat if the coal could be put in the bunkers already pulverised, and if it could be handled on board in this state. It is, unfortunately, necessary to carry the coal in the ordinary form of lumps on account of its liability to form an explosive mixture when in a powdered state, and it is therefore essential to pulverise the coal immediately preceding its combustion. This entails an extensive outfit of machinery, crushers, screens, conveyers, elevators, etc., in addition to the blowers, and turns the stokehold into a veritable machine shop. However this may be, the advantages to be expected from mechanical stoking on board ship—outside the questions of economy and smoke prevention — are so great that its disadvantages may perhaps be tolerated at some future date, especially on liners where the firing is regular and continuous, and where

all the boilers have to work at their full power, thus necessitating arduous and continuous labour on the part of a numerous *personnel.*

After repeated trials at sea all the various systems of mechanical stoking have had to be abandoned, and the human stoker with his shovel and rake again installed.

CHAPTER V.

LIQUID FUEL.

Specially written for this Edition by Engineer-Lieutenant H. C. Anstey, R.N.

54. *Early Experiments.*—Under the heading of Liquid Fuel may be included all the compounds of carbon and hydrogen which are fluid at ordinary temperatures, or which may be easily rendered fluid by the application of heat. Of these, however, the vegetable and animal fats and oils are not obtainable in sufficient quantity, and are in demand generally for other purposes, and, since they would only be used as fuel in exceptional circumstances, they need not be further considered. There remain the mineral hydrocarbons, of which petroleum is the chief; but shale oil, which is produced by the distillation of bituminous shale; tar oil, which is a bye-product in the process of distillation of coal gas; and blast furnace oil, a similar product from blast furnaces, are also used as fuel.

Some of the earliest experiments in this country in the burning of liquid fuel were carried out with tar oil by Mr. Holden on some locomotives of the Great Eastern Railway. Nearly forty years ago some experiments were also carried out by the British Admiralty with tar oil, but though the results of these latter experiments appeared to have given satisfaction at the rates of combustion required in the service at that time, the experiments were not continued, possibly because it was thought that on account of the uncertain supply of this fuel and its high price, the advantages which it possessed over coal were not such as to warrant even its partial adoption.

About this time also a steamer was fitted to burn tar oil, and a report of a trial run on the Clyde appeared in the *North British Daily Mail* of the 24th April 1868, but the details of the system are not given. It is interesting to note, however, that in those days liquid fuel was spoken of as the fuel of the future, a prophecy which is still repeated, but which is not likely to be fulfilled until the production is very largely increased.

Of recent years, however, the world's production of petroleum has been increasing steadily, and, in view of the many advantages of liquid fuel as such, the problem of burning it in the best possible manner for generating steam in a boiler has been forced upon the engineer.

The fact must not be lost sight of that, even at the present time, the production of petroleum throughout the world is only about three per cent. of the coal production, and that therefore the use of liquid fuel for power purposes is necessarily limited, and it cannot be expected to supersede coal except under special conditions. It has, however, possibilities as an auxiliary to coal for marine purposes by adapting the boilers either to burn oil or coal alternatively, or in conjunction.

55. *Advantages of Liquid Fuel.*—These advantages arise first from the higher calorific value of the oil over coal, so that a less quantity of it may be carried for a given radius of action, or conversely the same weight of oil will give an increased radius of action; and secondly, the use of a liquid fuel is at once a solution of the problem of mechanical stoking.

In the case of a merchant steamer the reduced bunker capacity required when burning oil gives an increase in the carrying capacity; in the case of a war vessel the increased radius of action given by oil over an equal weight of coal

should give that vessel undoubted superiority over a similar vessel carrying coal.

The mechanical stoking of coal has not been seriously entertained for marine purposes, as, principally on account of limitations of space, the difficulties of arranging satisfactorily for the mechanical conveyance of coal appear to be almost insuperable. With oil, however, not much extra space is required for the fittings necessary to deal with the oil, and they can be arranged readily in the space provided for stoking, while there is no difficulty at all in transporting the oil unless it be at low temperatures, as at those temperatures, it becomes too thick to be pumped. Practically all the oils, at present being used as liquid fuel for marine purposes, remain sufficiently liquid at all ordinary temperatures, though sometimes it is considered desirable to fit steam-heating coils in the storage tanks.

The advantages which follow directly from the satisfactory solution of the problem of mechanical stoking will be readily apparent. In the stoking of coal by hand on a marine boiler we are dependent very largely on the skill of the stoker in order to ensure that we get the full value out of the coal; the amount of manual labour also is considerable, not only in shovelling the coal into the furnace, but also in trimming it from the bunkers into the stokehold. In the case of oil burning, though a certain amount of skill is required in the adjustment of the oil "burners," so as to give the best result, they continue to work with little or no attention so long as the conditions remain the same; the labour, also, is reduced to a minimum as compared to that required in stoking, and trimming is entirely done away with. The frequent cleaning of fires is also obviated, thus enabling boilers with oil-burning appliances to maintain their full output of steam. For a ship of war this advantage is of the utmost importance, as it not only enables her to maintain her maximum speed for prolonged periods, but also

relieves the stokers of very trying work, especially in hot climates. In long-distance steaming it is the endurance of the stokers which measures the speed of the ship.

Other advantages of liquid fuel over coal are: it is possible to raise steam more rapidly, though this is to some extent dependent on the type of boiler employed; it is possible to increase the output of the boiler more rapidly as the oil is burnt as soon as injected into the furnace, and has not to be subjected to a process of comparatively slow distillation as in the case of coal; re-bunkering at sea is a much more simple and easy matter with oil than with coal; the absence of coal dust and ashes, and therefore less wear and tear of the machinery in the stokeholds; oil does not deteriorate as coal does by storage, this quality is of special value on foreign stations, where the coal obtainable is often small and of very inferior quality, the former resulting in loss by the dust falling through the grate bars, and the latter necessitating frequent cleaning of fires; and finally, there is a great saving in labour, and a consequent reduction in the *personnel.*

55A. *Petroleum Briquettes.* — Attempts have been made with more or less success by several inventors to solidify petroleum for use as fuel. Experiments, however, with petroleum briquettes have not generally been satisfactory, but even had they been so, it is difficult to see what advantages would be gained. On the contrary, when petroleum is solidified most of its advantages over coal disappear, leaving only the advantage of higher calorific value.

56. *Sources of Supply.*—Petroleum is found in practically every country in the world, but in a few districts only in sufficiently paying quantities. Until recently the oil fields of the Russian Caucasus and of Pennsylvania, U.S.A., supplied

the bulk of the oil for the world, but in the last few years oil has been produced in Roumania, Galicia, California, Texas, Borneo and Burmah, and in smaller quantities in several other countries. Oil has been distilled from shale in Scotland for many years, and the shale oils are very suitable for liquid fuel, but, unfortunately, the supply is not large, and the price is comparatively high. The liquid fuel which would be used in any particular country would depend upon the position of the country relative to the nearest oil-fields, and the facilities for transport from those fields. Thus, though the Russian fields are nearest to this country of those that produce fuel oil in considerable quantity, the cost of transport is such that the use of liquid fuel from Russia is commercially impossible. The opening up of the oil fields of Texas, which are more favourably situated, in relation to the coast, has made it possible to put this fuel oil on the English market at 35s. to 40s. a ton, or a little more than one-half the price of the Russian fuel oil "Astatki." Even at this price, oil fuel is considerably more costly to burn than coal, so that its general adoption in this country is not a matter of the immediate future. Its advantages for certain purposes are so great that they may reasonably be considered to balance the extra cost, and therefore its use in a limited sense is assured. In countries which have a natural supply of oil fuel, the conditions are of course different. Liquid fuel has been in use in the steamers on the Caspian Sea since 1870, and is now used there almost exclusively. Since the development of the Californian oil-fields, several steamers trading from Californian ports have been fitted to burn oil, and the performance of one of these will be referred to later. The opening up of the oil-fields of Borneo has enabled liquid fuel to be sold comparatively cheaply at Eastern ports, but on account of the cost of transport the use of Borneo oil is likely to be confined to the East.

57. *Properties of Petroleum.*—The petroleum, as it is obtained from the earth, is a dark-coloured fluid, generally mixed with water and earthly impurities. This is the crude oil, and when the production is greater than the facilities for refining, the crude oil is often exported for use as fuel. After the water and earthly impurities have been allowed to settle, the oil is subjected to a process known as fractional distillation. The oil is placed in a still, and its temperature is raised to a certain pre-determined point; after the distillate has been collected the temperature is raised to a further point. The extent to which this fractional distillation is carried depends upon the character of the crude oil, but generally the successive fractions comprise oils which may be classed under the heading—(*a*) Light oils or petroleum spirit; (*b*) Illuminating oils; (*c*) Lubricating oils. The residue which is left after the lubricating oils have been extracted is only of use as fuel; though it will be understood that, in certain cases, it may not pay to take the distillation beyond one or two of the above stages.

The Russian oils leave a comparatively large percentage of residue (Astatki); on the other hand, the Pennsylvanian oils give only a small residue. Texas oil again gives a rather large residue, and in this case the distillation is not usually carried beyond the lighting oil stage, as the quantity of lubricating oil which it contains is said to be insufficient to pay for its extraction. In Russia, Mazut is often used as fuel. Mazut is the crude oil which has been stored for some time in open reservoirs, and has lost thereby some of its more volatile constituents. Naphtha is another term applied to Russian liquid fuel, and is generally understood to mean the residue after the illuminating oils have been extracted.

The chemical properties of petroleum require a treatise in themselves.*

* For a full account, together with an explanation of the various methods employed in the distillation, the reader is referred to the valuable treatise on "Petroleum and its Products," by Sir Boverton Redwood.

It is sufficient here to note that the hydrocarbon compounds of which petroleum is composed consist of two main series, which are represented by the general formulæ $C_n\ H_{2n}$, which is called the olefine series, and $C_n\ H_{2n}+2$, which is called the paraffin series; there are also naphthenes represented by $C_n\ H_{2n}-6+H_6$ (which are isomers of the olefines), and benzines represented by $C_n\ H_{2n}-6$ and several other series. The olefines begin with $n=2$, giving $C_2\ H_4$ (olefiant gas), and the paraffines with $n=1$, giving $C\ H_4$ (marsh gas). These gases are given off in more or less quantities when the crude oil is drawn from the well, and they are especially abundant when the wells are of great depth, as is often the case in the Pennsylvanian oil district. This natural gas issues at considerable pressure, and is collected and distributed for lighting and power purposes. The members of these series are gaseous for low values of n, and in the paraffin series from $n=5$ to $n=26$ they are liquids, becoming denser and less volatile with the increase in the value of n, and at about $n=27$, and above they are solids. Their boiling points increase in arithmetical progression as n increases, the difference being 20° C (68° Fahr.) for each step in the series. Thus $C_8\ H_{18}$ boils at 117° C (243° Fahr.), while $C_{15}\ H_{32}$ boils at 257° C (463° Fahr.). The crude oil and the various distillates consist of many members of these series chemically combined, but in the Russian oils the naphthenes, and in the Pennsylvanian oils the paraffines, predominate. It will be seen, however, that, of whatever members of the series the oil is composed, the proportion of carbon to hydrogen is almost constant, that is, it is practically independent of the value of n, and this explains why very little difference is found in the calorific value of petroleum oils. Such difference as is found to exist is generally due to a small percentage of oxygen or some mineral impurities, of little or no calorific value (*e.g.* sulphur), which are often present.

The following are some typical analyses of fuel oils :—

TEXAS CRUDE—	
Carbon	84.6
Hydrogen	10.9
Sulphur	1.63
Oxygen	2.87
	100.00
Specific gravity	0.924
BORNEO CRUDE—	
Carbon	86.7
Hydrogen	10.7
Water	2.5
Nitrogen, Sulphur, and Ash	traces
Or after removal of water—	
Carbon	88.9
Hydrogen	11.0
Specific gravity	0.96
ASTATKI—	
Carbon	86.6
Hydrogen	12.3
Oxygen	1.1
	100.00
Specific gravity	0.94

The calorific value of the above samples calculated by Dulong's formulæ would be:

TEXAS	19,480 B.T.U.
BORNEO (omitting water)	19,720 B.T.U.
ASTATKI	20,100 B.T.U.

These values are confirmed fairly well by actual measurements in a "bomb" calorimeter, and also in practical experience.* As a general rule, the calorific value of

* That is to say if trials be carried out in the same boiler under exactly similar conditions, but with different oils, the evaporation per lb. of the several oils will be found to be proportional to their calculated calorific values.

petroleum liquid fuel does not vary greatly from 19,500 B.T.U., which is about one-third greater than the best Welsh coal. The calorific value of the tar and blast furnace oils are somewhat less than the petroleum oils.

It has been found that if distillation is carried on at a temperature higher than the normal boiling point (either by distilling under pressure or allowing the condensed distillate to fall back into the highly heated residue in the still) that the comparatively heavy oils undergo dissociation into lighter hydrocarbons of lower boiling points.

This phenomenon is known as "cracking," and is invariably accompanied by a deposit of carbon.

We shall have occasion to refer to it again in discussing the conditions of combustion of liquid fuel (section 60).

58. *Flash Point.* — The temperature at which oil when slowly heated gives off vapour in sufficient quantity to produce a momentary flash on the application of a flame, is called the "flash point" of that particular oil. If the oil is heated in a closed vessel for the determination of this point it is called a "close test," while if the vessel is open, it is called an "open test." In the same oil different results will be obtained by the two methods, and it is possible also to obtain different results by the same method by varying the conditions. The flash point is therefore an arbitrary test, but, if carried out under fixed conditions, it forms a reliable method of comparison of various oils as regards the proportion of the lighter and more volatile hydrocarbons contained in them. The extent to which these lighter and more volatile hydrocarbons are present determines the amount of vapour which will be given off under certain conditions, and thus the flash point gives indication of the relative amount of risk involved in the storage and handling of different oils. In this country the close test is generally adopted, and the instrument for determining it is the "Abel,"

tester, or some modification thereof. The Abel tester is used in connection with lighting oils, but the "Pensky-Martens" modification is more suitable for testing liquid fuel of fairly high flash point.

The principle of both instruments is the same. Oil is heated in a metallic cup having a closely fitting cover, which has holes in it; these holes can be covered and uncovered by a slide. The oil-cup is surrounded by a water-bath or air-space to ensure that the heating shall be gradual and uniform. On the cover of the cup is placed a small flame, which can be tilted by moving the slide, bringing the flame through a hole in the lid to the space below. Two thermometers are used, one in the water and one with its bulb just covered by the oil. The test flame is applied once for every rise of one degree in the Abel instrument, and when the flash takes place the temperature of the oil is taken as the flash point. The open test gives a flash point about 20° or 30° Fahr. higher than the close test.

A knowledge of the flash point of a liquid fuel is essential to the consideration of its suitability for marine boilers. As a general rule, crude oil has a low flash point, occasionally below the freezing point of water; more frequently at about ordinary atmospheric temperature; when obtained from near the surface of the earth it may have a flash point up to 300° Fahr. An oil having a flash point below ordinary atmospheric temperature is too dangerous to carry as fuel under ordinary circumstances. For a warship this point is of far more importance than in a merchant steamer, as, in the event of fire or explosion, more serious consequences would ensue. Moreover, in a warship, on account of limitation of space and intricate sub-division of compartments, there is a greater possibility of the collection of inflammable gases. The Admiralty have fixed 200° Fahr. as the minimum flash point of the oil to be carried as liquid fuel, while the rules of Lloyds' Survey require that in ships coming under their

rules carrying liquid fuel the flash point must not be less than 150° Fahr. and the American Navy Liquid Fuel Board recommend 175° Fahr. Even with oils such as these vapour may be expected to form, but not in sufficient quantities to be dangerous if the tanks containing the oil are properly ventilated. The danger incurred in the storage of low flash point oil is exemplified in the explosion which caused the loss of the s.s. *Progreso* at the Works of the Fulton Shipbuilding and Engineering Company, San Francisco, on 3rd December 1902.

At the time of the accident the vessel, which had been undergoing alterations necessary for fitting her as an oil carrier and burner, was having steam raised for a trial, and the fuel tank contained about one-sixth of its volume of oil. When the explosion occurred, the top of the fuel tank was forced upwards, and the ship's sides outwards, thus breaking the vessel in two at that point, causing the death of twelve persons, and injuring seriously ten others.

From the evidence taken after the accident, it appeared that the oil in the fuel tank contained $3\frac{1}{2}$ per cent. of low grade gasoline (petroleum spirit), and $6\frac{1}{2}$ per cent. of other distillates; it had a flash point of 85° to 101° Fahr., and a burning point of 138° Fahr., with a specific gravity of 0.917.

The actual cause of the ignition of the gas given off by the oil was not ascertained, but it seemed to be established that the oil had been mixed with a lighter oil to make it flow more easily, that lighted forges had been in use between decks, and that hot rivets had been driven into the hull that morning in the vicinity of the fuel tank.

59. *Ventilation and Storage.*—The nature of the ventilation required depends to a large extent upon the method of storage. In an ordinary merchant steamer fitted to burn liquid fuel, a part of the hold would be appropriated and sub-divided by transverse bulkheads into tanks of convenient

size. A longitudinal bulkhead would generally be fitted to minimise the effect on the stability of the ship caused by the movement of the liquid fuel in the tanks when the vessel is rolling. A coffer-dam would also be fitted, not less than 2 ft. in width, at each side of the fuel space, which would generally be kept empty and well ventilated, so that at any time the state of the confining bulkheads could be ascertained. This coffer-dam also serves to prevent any leakage into the hold space or machinery compartment.

If warships are built in the future to burn oil alone, some similar arrangement would probably be necessary. The storage of liquid fuel in side bunkers, as in the case of coal, would be open to many objections, the greatest being probably that it is very undesirable to have the fuel above the level of the furnaces, unless the fuel-bunkers are separated from the stoking spaces by a coffer-dam or air-space. This coffer-dam or air-space, if arranged along the longitudinal bulkheads, would mean considerably more waste of valuable space than if arranged transversely, and, moreover, the chance of a shot penetrating both the transverse bulkhead and the coffer-dam would be greater.

It would appear, therefore, that the arrangement of compartments of a warship to burn liquid fuel alone would differ materially from the present arrangements with coal.

Up to the present time, in large war-vessels, liquid fuel has only been used as an auxiliary to coal, and sufficient storage room is found for it in the double-bottom compartments. Probably from 400 to 600 tons could be carried (according to the class of ship) if all the double-bottom compartments were utilised for this purpose, but some would generally be reserved for the reserve feed-water for the boilers, as well as empty compartments between the oil and water tanks to ensure that no oil can leak into the water compartment, and thence be pumped into the boilers. The quantity stated above could be increased

readily, to give the equivalent of the normal coal-carrying capacity, by increasing the depth of the double-bottom compartments, but from the point of view of the naval architect, this would be a doubtful expedient. The carrying of so large a quantity of fuel low down in the ship would affect seriously the range of stability in the fully laden and light conditions. If the ship were designed to give a normal range of stability in the light condition the metacentric height with tanks full would be increased to such an extent as to make the ship a very unstable gun platform. If, however, the ship be designed to have its normal range of stability in the fully laden condition, the stability would be endangered in the light condition. It is true that the latter circumstance could be obviated by the admission of water ballast as the oil fuel is used, but this again has the disadvantages that it necessitates carrying useless weight about with the ship, and also it is improbable that the water would be entirely removed from these compartments, without considerable trouble, when it is desired to fill them again with oil, and the mixing of water with the oil operates very adversely in the burning of the latter.

As regards ventilation, in a merchant steamer with storage tanks of fairly large capacity probably several supply and exhaust pipes would be fitted to each compartment, they are taken well above the upper deck and their open ends protected to prevent any *débris* falling into the tank. An expansion trunk is sometimes fitted to prevent any appreciable pressure head coming on to the top of the tank, and ventilating pipes may be connected to it. Where the fitting of an expansion trunk is impracticable as in a double-bottom compartment, care should be exercised, in filling, to leave sufficient room for the expansion of the oil due to any subsequent rise of temperature. About five per cent. of the capacity of the tank is a usual allowance. When oil is stored in the double-bottoms a single ventilating

pipe of comparatively small diameter will probably suffice for each compartment, but the compartments under boilers should receive special attention to ensure the ventilation being adequate. The pipes should be under protection as far as practicable, and carried to some distance above the upper deck.

The following extracts from the "Rules of Lloyds' Register" for vessels burning and carrying liquid fuel, bring out the above and several other points:

"Each compartment must be fitted with an air-pipe always open discharging above the upper deck. Efficient means must be provided by wells and sparring or lining to prevent any leakage from any of the oil compartments coming into contact with the cargo or into the ordinary engine-room bilge. The pumping arrangements of the oil fuel must be absolutely distinct from those of other parts of the vessel.

"If the fuel is sprayed by steam, means must be provided to make up the fresh water used for this purpose.

"If the oil fuel is heated by a steam coil the condensed water should not be taken directly to the condenser, but should be led into a tank or open funnel mouth, and thence led to the hot well or feed-tank."

Some interesting points regarding the storage of liquid fuel were emphasised in an account which has been published of the grounding of the German battleship *Kaiser Friederich III.*, in April 1901. At the time of the grounding the fuel tanks in the double-bottom were filled with the usual quantity of heavy creosote oil, and the reduction of capacity in these tanks, caused by the inward movement of the skin of the ship, gave rise to a considerable pressure in them. Apparently the ventilating pipes, which, except in one compartment, discharged above the superstruction deck, were not of sufficient area to relieve this sudden rise of pressure as they burst in one stokehold at a point about on a level with the tops of the boilers. These pipes were carried near the boilers, and the escaping oil ran over the boiler fronts, causing a serious fire. In another compartment which had become flooded, oil ignited on top of the

water, but did not continue to burn, owing to the cooling action of the water. The pumps were situated in a single compartment, and as this became flooded there were no means of pumping the oil overboard had it become desirable to do so.

60. *Combustion of Liquid Fuel.*—The conditions required to burn liquid fuel with maximum efficiency differ considerably in detail from the conditions in coal burning. The same general principles are, of course, involved in each case; that is to say, there must be, firstly, an initial temperature sufficiently high to start combustion; and, secondly, the fuel and the element supporting combustion must be brought into sufficiently intimate contact to ensure that the combustion is continuous and complete. When combustion is once started, the first condition presents no difficulty, and in the case of coal burnt upon a grate, the second condition resolves itself largely into a question of the skill of the stoker in maintaining his fire at a suitable and uniform thickness, but the size of the combustion-chamber has also an important influence on combustion. Whereas coal is burnt by stages, commencing with the more volatile constituents and ending with the fixed carbon, liquid fuel has to be burnt practically as soon as it is injected into the furnace. The result of this is, that the volume of gases to be dealt with is much greater than in the case of coal, and the problem of securing their intimate mixture with the air for combustion is increasingly difficult. This explains why high rates of smokeless combustion with liquid fuel are difficult to obtain without large combustion space, and generally, in comparing the merits of the different systems of burning liquid fuel, the amount of oil burnt per cubic foot of combustion space should be taken into consideration, as well as the results obtained in evaporation per lb. of oil. In ordinary cylindrical merchant service

boilers the amount of oil to be burnt per cubic foot of combustion space per hour does not as a rule exceed from $2\frac{1}{2}$ to 3 lbs. while in naval boilers about double this quantity must be burnt, and therefore the data obtained from merchant service practice is of little service to the naval engineer as indicating the direction in which smokeless combustion with liquid fuel must be sought.

Part of the difficulty in obtaining smokeless combustion is no doubt due to the "cracking" of the oil which has been referred to previously. When the oil is injected into the furnace it is subjected to a heat greater than its normal boiling point, with the result that it is decomposed, and liberates a certain proportion of carbon, which is in a very finely divided condition. Unless this finely divided carbon is burnt before it comes in contact with the comparatively cool plates and tubes of the boiler, it is practically certain to pass away unconsumed, and a very small quantity is sufficient to give the appearance of dense black smoke. It has been noticed that in forcing a locomotive boiler the limit of smokeless combustion is reached when the flame begins to enter the tubes.

It is the custom of inventors of liquid fuel burners to lay stress on the completeness with which their particular burner "atomises" the oil. No doubt something is to be said for the fineness of a spray, but this is not the most essential feature required for perfect combustion. It will be seen from the chemical compositions given previously that about 15 lbs. of air are chemically necessary for the complete combustion of each lb. of oil, and if the oil is broken up into drops, however fine, each globule of oil would have to be surrounded by a sphere of air necessary for its combustion over twenty times its diameter. If, therefore, reliance were placed on atomisation alone, a very large quantity of the oil would never meet with its corresponding amount of air. A more reasonable view appears

to be that atomisation is only useful as a preliminary to vaporisation, and this is probably the explanation why attempts to burn cold oil fuel, except at low rates of evaporation, have been attended frequently with immoderate smoke.

When the oil undergoes a preliminary heating, as is the case in all modern successful installations, the vaporisation is effected early in the furnace, giving rise to a short flame, and giving a greater chance for mixing and burning the liberated carbon. With a long flame combustion is delayed, and often only completed in the funnel itself, resulting in flaming and high funnel temperatures. The conditions attending the use of forced draught favour the combustion of liquid fuel, as the velocity energy of the air entering the furnaces promotes more rapid mixing, but the tendency under these conditions is for a large excess of air above that chemically necessary, and consequently an increase in the heat rejected in funnel gases. This can be partially corrected by restricting the area of the uptake, but at the expense of increased work on, and steam consumption in, the fans for forced draught.

Heating of the oil should take place as near the furnace as practicable, and should be as high as safety permits, but not so high as to cause the oil to "crack," and carbon to deposit in the supply pipes. It should be pointed out that if the oil is heated to its burning point, or fire point (*i.e.*, the temperature at which it takes fire on the approach of a flame and continues to burn), danger is incurred in the event of a leaky joint in the oil pipes. The burning point is some 50° Fahr. or more above the flash point, according to the class of oil, so that if the preliminary heating is limited to the temperature of the flash point, safety is practically assured except in the case of a very bad leak involving the liberation of a large quantity of hot oil. In some systems, heating coils are fitted in the gravity or

supply tanks, the object being to separate out any water which may be in the oil, the rise of temperature reducing the density of the oil, which therefore rises the more rapidly and floats on top of the water. This heating should, however, for safety, be limited to about 50° Fahr. below the flash point, the size of the steam-heating coils being proportioned so that this temperature cannot be exceeded, and further, the tanks should be closed and provided with ventilating pipes of ample size carried to the upper deck.

61. *Types of Burners.*—Nearly all modern oil burners operate by spraying the oil by the agency of either steam, compressed air, or the pressure of the oil itself.

In some of the experiments of forty years ago attempts were made to burn the oil from a free surface, but obviously this system is limited by the comparatively small surface which it is possible to expose to the action of the air, and hence it is only suited to very low rates of combustion. Several arrangements on this system have been tried, but may now be considered of historical interest only.

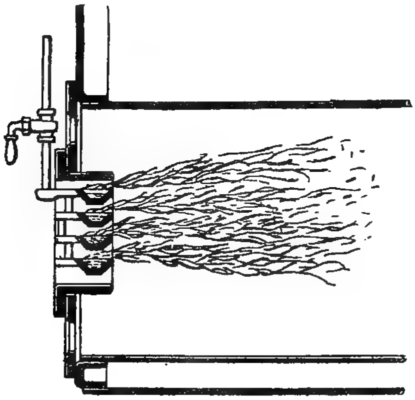


Fig. 38.

One form which is illustrated in Fig. 38 is known as the "cup-grating" burner. Its general features will be apparent from the sketch. The oil runs by gravity through the vertical pipe shown, and fills the troughs placed one above the other, arranged in an opening in the furnace front. It need hardly be mentioned that, apart from the low rate of combustion possible with this form of burner,

the arrangement is scarcely suited for the confined space of a ship's stokehold. In another form of free surface burner tried by Richardson in 1864 the bottom of the furnace was lined with refractory material and the oil run into it by a pipe. The oil spreading through the lining exposed a greater surface and an increased rate of vaporisation of the oil was effected. The air which entered through the furnace front passed over the surface, and its rate of

RICHARDSON'S METHOD OF BURNING OIL FUEL.

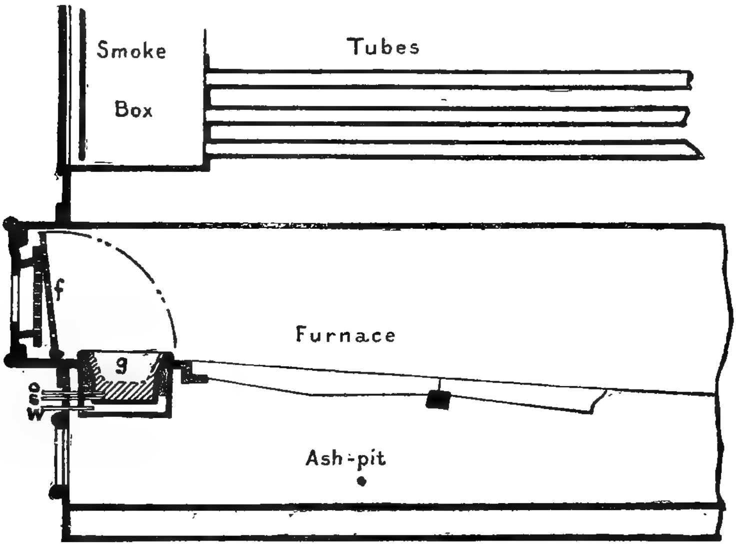


Fig. 39.

mixing with the oil vapour was accelerated by means of steam jets.

A modification of this system, also designed by Richardson, is illustrated in Fig. 39. In this an attempt was made to burn oil as an auxiliary to coal. It consisted of a trough "g" with a water-jacketed bottom, arranged just inside the furnace mouth, and lined with refractory material. Oil was run into the trough by the pipe "o," and steam blown through the oil by the pipe "s"; "w" is a water connection

to the bottom of the trough, and "f" is a portable plate which could be let down over the oil trough, when it was desired to fire up with coal.

61A. *Steam-Spraying Burners.* — It became evident after many attempts had been made to burn oil from a free surface, that some different system was necessary if an increased rate of combustion of the oil was to be obtained. Two essentials were necessary before any progress could be made, the first being to increase largely the surface of the oil to be burnt, and the second to secure a more complete mixing with the air introduced for combustion. Both these essentials were obtained by the introduction of the "steam-spraying" burner, and the system of spraying oil by steam is still the one which is the most general. The effect of the steam spray is to break up the oil into very fine drops, thus presenting a very large surface, while at the same time it induces a current of air, which, if properly directed, adds considerably to the mixing effect.

All steam-sprayers are designed on the same general principle. There are two orifices, through one of which oil flows under a slight pressure, usually due to a head, while from the other steam issues in such a manner as to impinge upon the oil-stream and break it up into spray. The two orifices may be side by side or concentric, and are generally of rectangular, circular, or annular form. The majority of steam-burners now made work on the injector principle, the steam jet inducing the flow of oil, or in effect adding to the available head.

Burners with rectangular openings, sometimes called "slot burners," are not much used for marine boilers, but they are frequently employed for locomotive work, especially in America. The slots are long and narrow, placed horizontally one above the other, the oil-opening being at the top and of much larger area than the steam-opening. This type

of burner has been used on the locomotives of the Santa Fê railroad in California, and is illustrated in Fig. 40.

A burner of this type, known as the "Booth" burner, was tested by the American Liquid Fuel Board, and the results are given in their recently published Report. Under natural draught good results were obtained, the evaporative efficiency on two trials being respectively 13.39 and 12.88 lbs. of water from and at 212° Fahr. per lb. of oil. With forced draught, however, the efficiency fell off rather rapidly, varying from 9.52 to 11.19 lbs. of water from and at 212° per lb. of oil with an air-pressure up to 3 ins. of water.

Burners with circular nozzles are sometimes arranged with the orifices side by side, but more often they are made

Fig. 40.

concentric. In such cases either one orifice forms an annulus around the other, or both orifices may be annular. The steam may issue from the central orifice and the oil from the annulus, or *vice versa*, according to the fancy of the designer. One of the earliest of the steam-spraying burners with orifices for steam and oil side by side was that designed by Aydon & Selwyn in 1867, and tried under the direction of Admiral Selwyn at Woolwich in 1868 with satisfactory results up to the rates of combustion then required for marine boilers. The flow of oil was regulated by a cock in the oil pipe, while the steam was regulated by a screwed spindle. This burner was provided with a circular extension piece around the nozzles, having an opening through which air could be drawn by the action of the steam jet. Fittings of

this description doubtless add to the efficiency of the mixing, but they have the disadvantage that they burn away rapidly under the influence of the high temperature, which is obtained a few inches away from the mouth of the burner.

One of the earliest burners of the injector type perfected was that of Urquhart, and it was fitted to the locomotives of the Griazi-Tzaritzin Railway in Southern Russia. In this burner the steam issues through the central tube while the oil flows round it. The central tube is tapered at the end, and fits a nozzle through which the oil and steam together are ejected. The oil opening can be adjusted by moving the central tube by the screw and gearing "o" (Fig. 41).

Another burner of the "injector" type which has been applied largely to locomotives, and which has been used also for marine boilers, is that of Holden (Fig. 42). In this burner both the oil and steam passages are annular, formed between the surfaces of concentric cones, and open into a nozzle which has two outlets with their axes inclined. The central passage is, in this case, left open, so that a small current of air is introduced through it. The mixed air, oil, and steam issue through the openings in the nozzle, and the mixture is still further acted upon by fine jets of steam issuing from small holes drilled in a ring "r" surrounding the burner, these jets also inducing a further current of air. The admission of air through the central tube is not capable of regulation, but as it is of small cross section, the quantity of air passing through it must be very small compared to the quantity of air required for combustion. The steam supply to the ring "r" is adjusted by the cock, and that to the injector by moving the central cone "a"; the oil supply is regulated by valves "o" and "o′" external to the burner, of which "o" is the main oil regulating valve, and "o′" is an auxiliary valve to augment the oil supply.

URQUHART OIL FUEL BURNER.

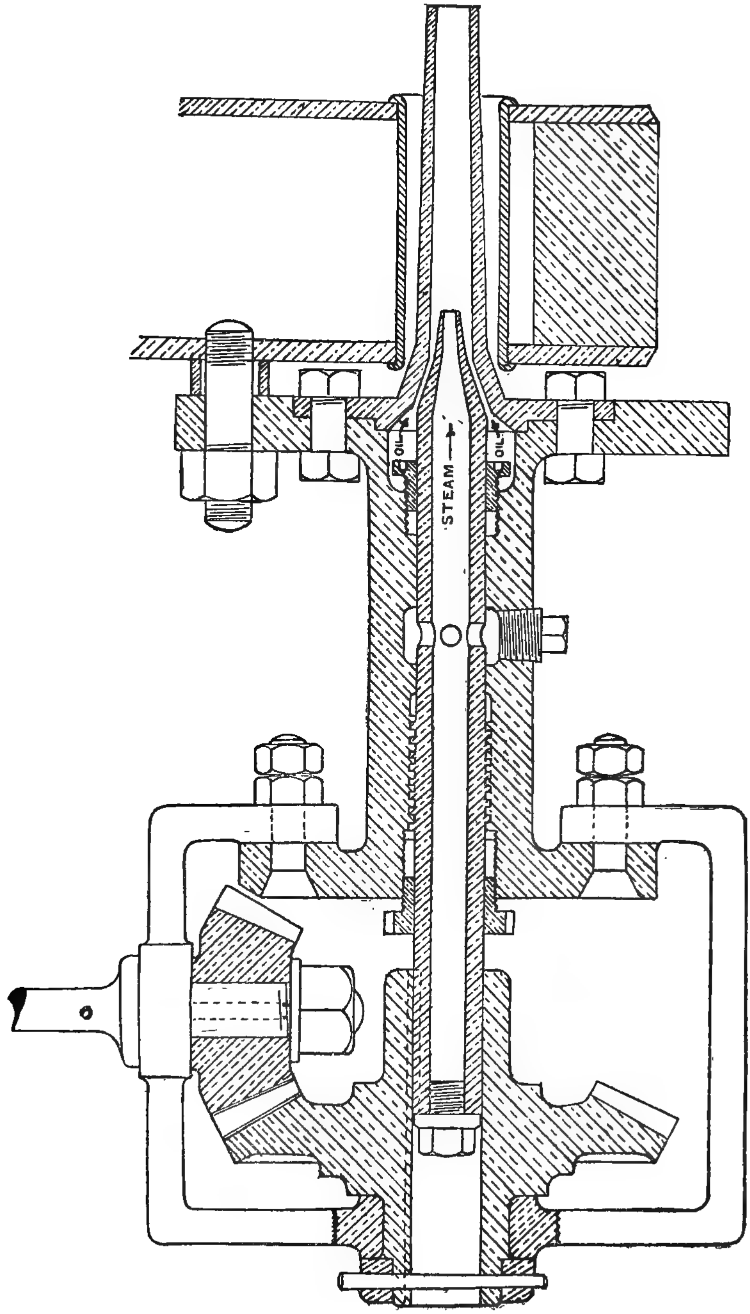


Fig. 41.

In the "Rusden & Eeles" burner, which has been fitted to the boilers of several steam-ships, both passages are annular, but the opening at the burner nozzle of both steam and oil

HOLDEN BURNER.

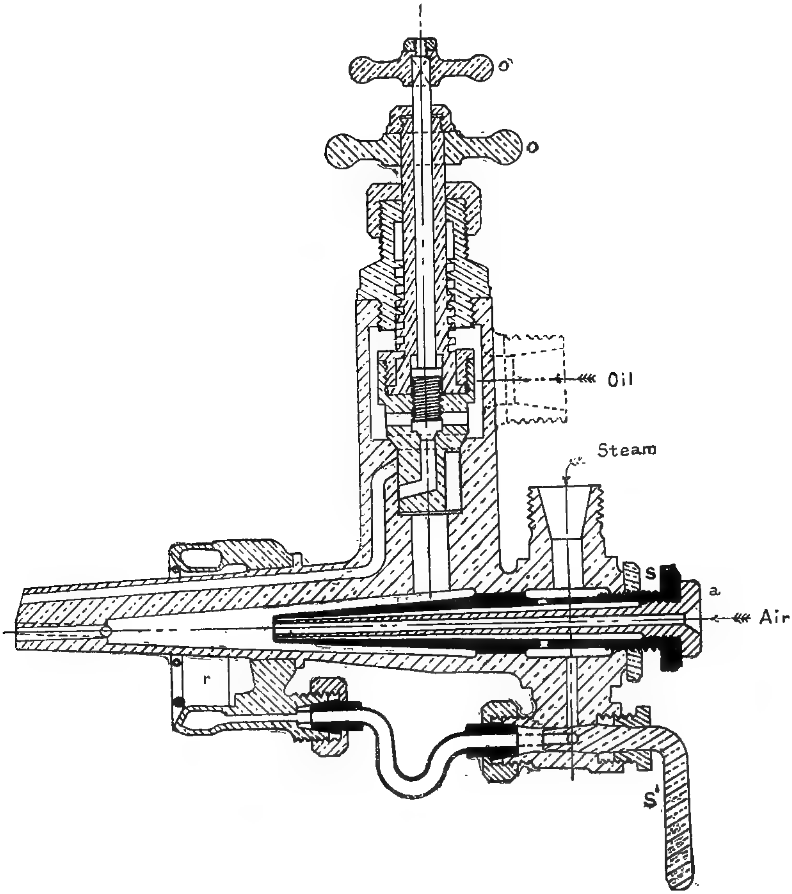
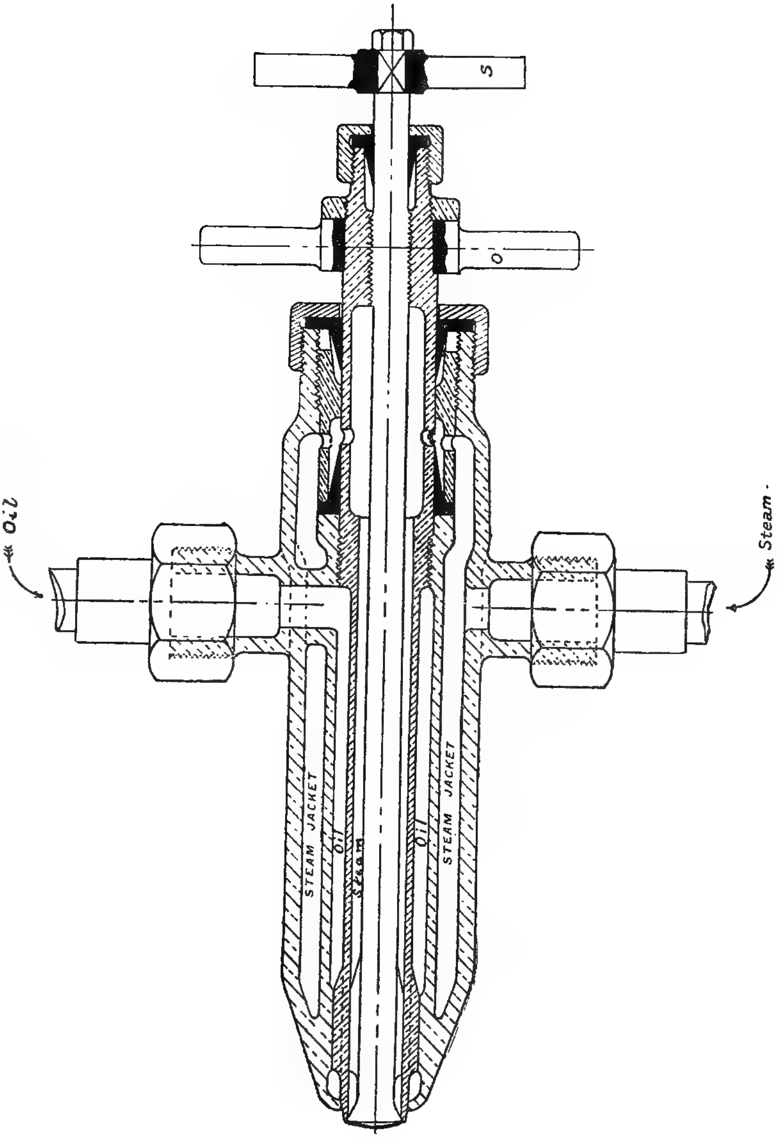


Fig. 42.

can be regulated separately, the oil by "o," and the steam by "s." The construction will be readily followed by reference to the illustration (Fig. 43).



Rusden & Eeles Burner.

Fig. 43.

In the "Niclausse" steam-spraying burner there is a small steam tube surrounded by an annular oil passage, while round this again is the main steam jet (Fig. 44). The oil thus leaves the burner as a cone, having a cone of steam in the centre and being surrounded by a cone of steam externally. The general construction of this burner is shown below. The steam supply to the main jet is regulated by the wheel "s," that to the central tube being constant, and the oil is regulated by the handwheel "o"; the tube "c" is telescopic.

61B. *Air-Spraying Burners.*—Speaking generally, burners which are suitable for working with steam as the spraying agent may also be worked with compressed air. Steam burners are, however, designed to work with a fairly high pressure, say 60 to 70 lbs. per square inch as a minimum. Air at this pressure would necessitate the use of air-compressors of comparatively large power, which would therefore entail a considerable steam consumption, and though this steam would be recovered in the condenser, and not lost in the funnel, as in the other case, its expenditure means a diminution of the net amount of steam available for the propulsion of the ship. For this reason, therefore, what may be termed the high pressure air-spraying system is not in favour. Another reason why high air-pressures are undesirable for spraying lies in the fact that air, in expanding, falls in temperature, and this would tend to cool the oil, and delay, if not prevent, combustion. Where a high pressure air-spraying system is adopted it is usual to heat the air considerably by passing it through tubes in the uptake. The power required for the air-compressor diminishes as the pressure is reduced, and in the air-spraying systems it is not usual to use a pressure above 30 lbs. per square inch. Even with this pressure the plant required is relatively bulky. In the s.s. *Mariposa*, the

NICLAUSSE BURNER.

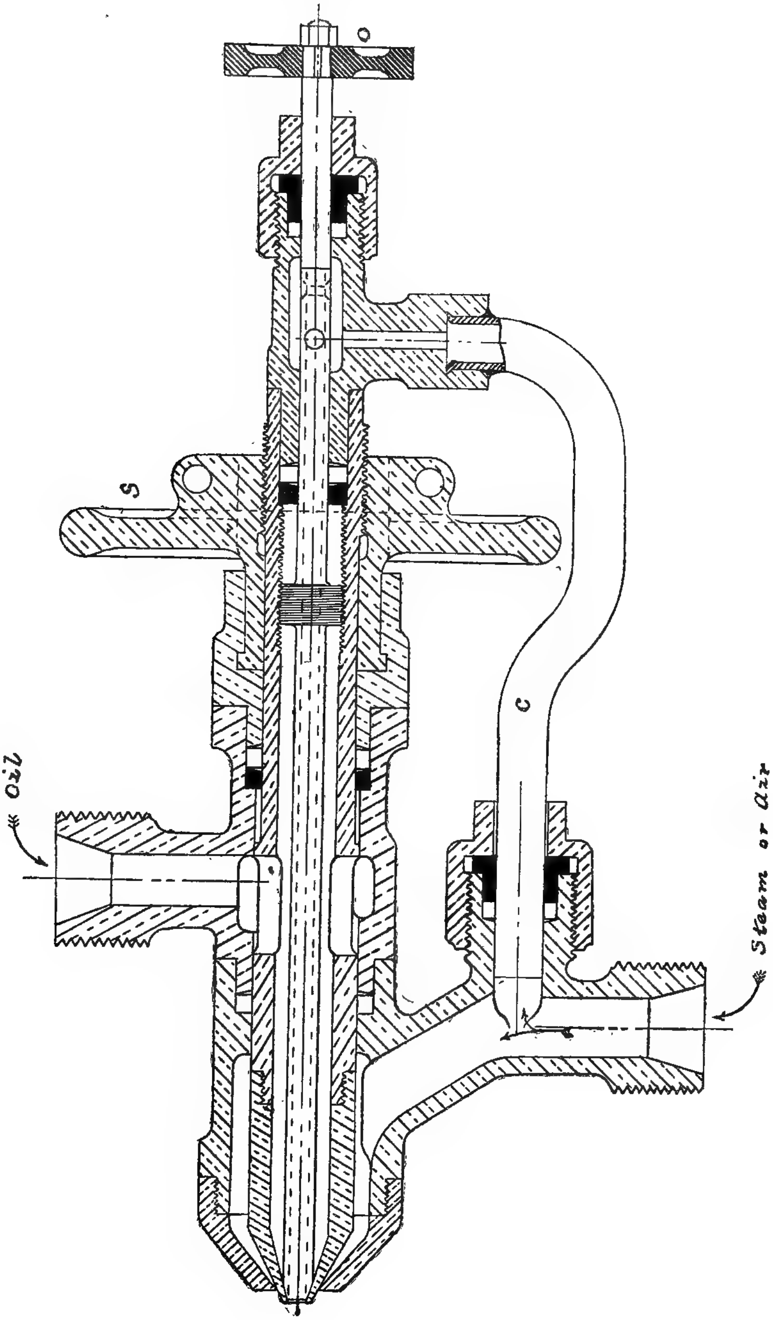
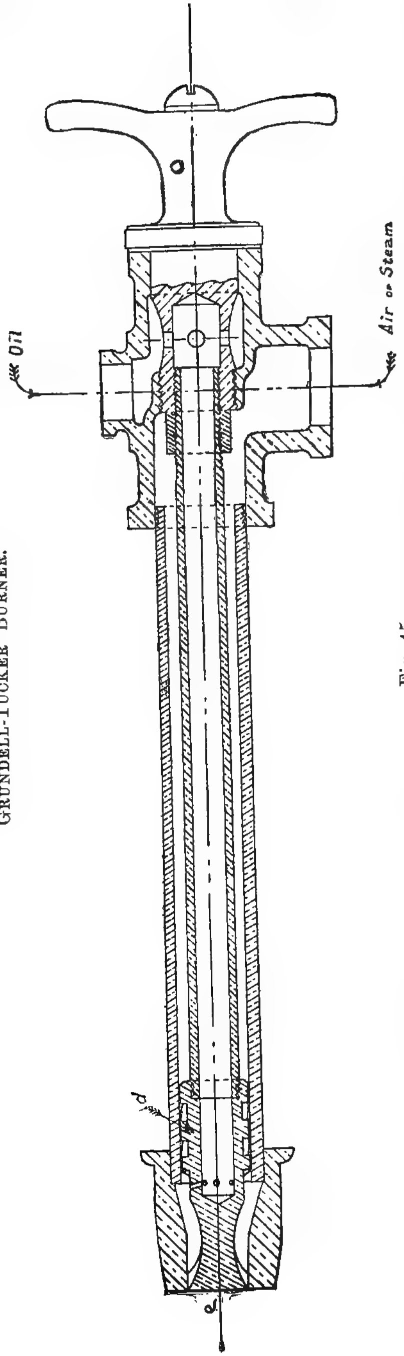


Fig. 44.



Grundell-Tucker Burner.

Fig. 45.

performance of which is referred to in the Report of the American Liquid Fuel Board, published in 1902, the pressure of the compressor was 30 lbs. per sq. in. The burner used, which is known as the "Grundell-Tucker" burner and appears to be simple and effective, is illustrated in the Report, and is here reproduced (Fig. 45). The oil in this case enters the central tube and emerges through twelve fine holes $\frac{1}{32}$ in. in diameter near the end of the tube, and almost at right angles to the central tube. The air enters the annular space between the central tube and the outer casing of the burner, and has to pass through a number of spiral grooves "d" formed on an enlarged part of the central tube. These give the air a whirling motion, after which it meets the issuing jets of oil, breaking them up into fine spray, which then passes through the

burner nozzle "e." The air is heated by compression, and also by passing it through a hollow casing on the furnace front on its way to the burner.

Another air-spraying burner with which a number of tests were made by the Liquid Fuel Board, is the "Oil City Boiler Works" burner (Fig. 46). The air for spraying in these trials was taken from a "Roots" blower, and varied in pressure from .78 lbs. to 4.68 lbs. per square inch. The construction of this burner will be apparent from the annexed sketch. The oil is regulated by the wheel "o," and the air orifice by the wheel "a." With this comparatively low pressure, the spraying of the oil was apparently satisfactory, as it was possible to obtain with forced draught a greater evaporation per square foot of heating surface than was obtained with coal. This is interesting, as showing that high-air pressures for spraying are not really necessary. It would be possible by using ordinary high-speed fans in series or by turbine compressors to obtain such comparatively small pressures as those used in the above quoted trials without recourse to plunger compressors, which, on account of their limited speed, are necessarily bulky and expensive. The use of low pressure air systems in this country has not received the attention it deserves, but one system at least, that of Kermode, has been tried on a limited scale with satisfactory results (Fig. 47). The general arrangement of this burner is here indicated. The oil enters the burner as shown, and the supply is regulated by the valve "o." Compressed air enters as marked, and part passes through the central tube, inducing, mixing with, and heating the oil, and the remainder passes through the outer casing, and pulverises the oil. The air is regulated by means of racks and pinions "a" and "a′", and in each passage is a spiral or helix, placed to give the passing fluid a rotary motion and to promote intimate mixing.

Several burners have been designed and tried using

Oil City Boiler Works Burner.

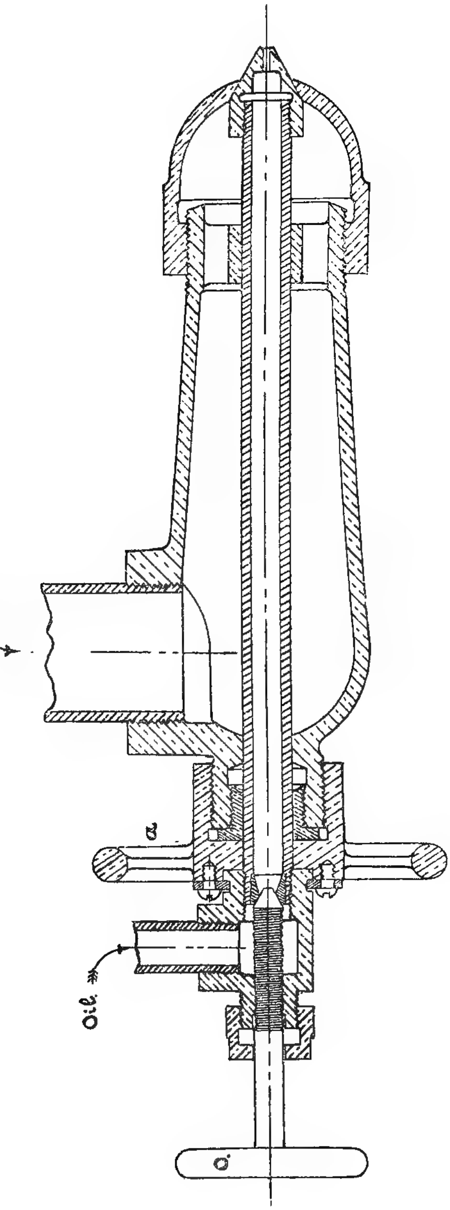
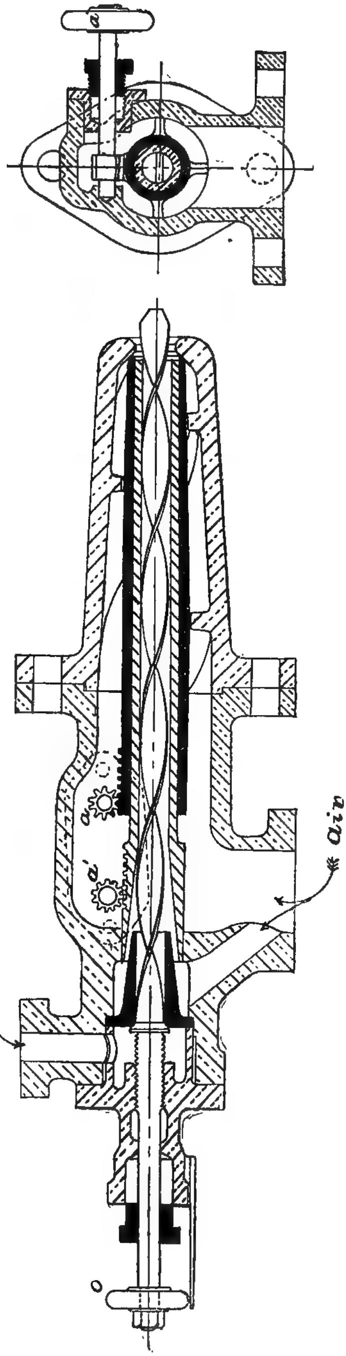


Fig. 46.

combined air and steam for spraying, that is to say, the air has been pumped or blown, and not merely induced by the steam jet. The results, however, have generally not justified the extra complication, and as satisfactory results can be obtained with either spraying medium, the use of both together appears unnecessary. In this connection the American Liquid Fuel Board in their Report remarks:—"Apart from any question of furnace efficiency, the Board considers the combined use of both air and steam in the burners is undesirable. Such an installation involves unnecessary expense and complication, and requires much more attention in the adjustment and manipulation of the burners." With this view most engineers will agree.



KERMODE BURNER.

Fig. 47.

61c. *Vapour Burners.*—Attempts have been made to convert the fuel into

a gas or vapour in a retort heated vessel or coil before injecting into the furnace. But for the property of petroleum oils of "cracking" and depositing some of their carbon, this system would in all probability be the most satisfactory, as it would enable complete combustion to be obtained with very little trouble, and, moreover, the quantity burnt would be regulated with great exactitude. If a fairly light and refined oil is used, satisfactory results are obtained for a time, but with the heavier oils the burner becomes quickly choked with carbon. For continuous steaming, such as required for marine boilers, vapour burners cannot therefore be regarded as likely to lead to a satisfactory solution of the problem of burning liquid fuel. Their use has hitherto been chiefly confined to the steam boilers of mechanically propelled vehicles in which refined oils are used. They have, however, also been applied to the boilers of small yachts.

61D. *Pressure Sprayers.*—It is well known that when a fluid is caused to change its velocity suddenly, the tendency is for eddies to be formed, and this is specially noticed when the change is made by a sudden increase or decrease in the diameter of a pipe through which the fluid is flowing, the change of velocity being accompanied by a loss of head. This loss is accounted for by an increase in the energy of rotation of the particles of the fluid which do not continue to follow definite stream lines as in the case of a straight pipe of uniform section.

In the case of a pipe discharging into the atmosphere we can consider the change to be from a defined or given cross-section to one of indefinite area, and it is a matter of common observation in the case of an ordinary water-tap, where the water issues under considerable pressure, that after leaving the mouth of the tap the water spreads out and breaks up into drops. This principle is made use of

DUPLEX BURNER OF THE KÖRTING TYPE.

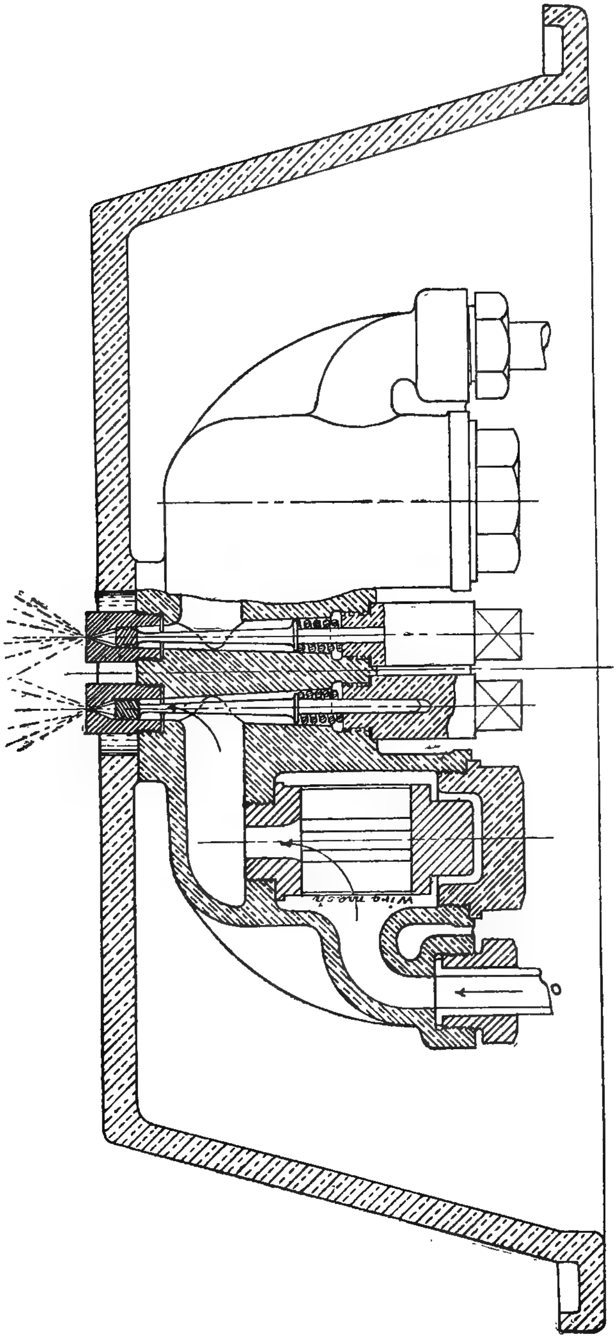


Fig. 48.

in pressure-sprayers, where the oil is forced under considerable pressure through very fine openings. It will be seen that the higher the pressure, the smaller will be the size of opening required to discharge a given quantity in a given time, and no doubt the best results are obtained with the higher pressures, as the amount of energy of rotation imparted to the particles is greater, or, in other words, the spray is finer. The spray-holes, however, should not be made too fine, or they easily become choked and the burner rendered inoperative. It is further desirable to provide strainers of very fine mesh between the pump and the burner. Even with this precaution there is always the possibility of choking by a deposit of carbon in the spray-hole, and the nozzle therefore should be readily detachable for cleaning, so that in case of failure of the spray a spare nozzle can be shipped in a short space of time. The strainers should also be arranged so that they can be changed with equal facility. The opening being so small makes these burners rather more delicate in adjustment than either air or steam-sprayers, and this fact, together with the mechanical disadvantages mentioned above, probably accounts for their limited use compared with the latter types.

The best-known pressure-burner is that of Körting. This sprayer consists of a spindle, near the end of which is a multi-threaded plug screw. The threads are square, and the top of the thread just fits the spraying nozzle. The oil to be sprayed has to pass round the grooves between the threads. At the end of the thread the spindle is formed into a cone, and opposite the apex of the cone is the spray-hole. The oil has thus to change its velocity several times before being discharged, and in addition is given a whirling motion in passing through the grooves of the screw, conditions which favour the breaking up into spray. This construction will be followed by reference to the illustration

of the Körting sprayer fitted in the s.s. *Tebe* (Fig. 48). It will be noticed that the sprayers are fitted in duplicate, and arranged so that either can be disconnected while the other is at work. In a pressure-burner the fineness of the spray depends to some extent on the viscosity of the oil, and it is desirable that the oil should be heated to as high a temperature as practicable. This heating, however, should be carefully regulated, otherwise carbon may deposit in a finely divided state, and choke the strainer, if not the spray hole. In an account of the trials of the s.s. *Tebe* which has been published recently, it is stated that the inconvenience of the obstruction in the strainers was so frequent that the strainers were removed, and reliance placed only on the strainers in the suction pipe to the pump. It is well to remember that oil is a very bad conductor of heat, and it is possible to overheat it locally in the heater while giving only the desired temperature at the burners. Steam-heating coils should therefore be of large area, and the whole of the oil passing through the heater should come in contact with some part of the heating surface.

62. *Comparative Merits of Steam and Air Pressure for Spraying.*—As regards simplicity, steam has the advantage, since no pump is required; but it has the serious disadvantage that the burners cannot be started, unless steam is first raised by a coal fire, or steam supplied to the burners from another boiler. This disadvantage also applies to air-spraying, but with the pressure system the oil could be pumped by hand until sufficient steam is raised to work the oil pump. As regards economy, though each system may be made to give practically the same evaporative results per lb. of fuel, the nett result will be in favour of the pressure system. Let us compare the results to be obtained from each system, taking coal as a standard, and assuming that a given quantity of coal is made to evaporate 100 lbs. of water.

Assuming the boiler efficiency to remain the same, the same weight of liquid fuel will evaporate a quantity of water in proportion to the relative calorific values of liquid fuel and coal, that is to say, about 135 lbs. Now in the case of coal burning, the whole of the 100 lbs. of water evaporated is available for use in the engines of the ship, but in the case of the liquid fuel, deductions have to be made for the steam used in heating the oil, and also for the steam used, either directly or indirectly, for spraying the oil. In steam-spraying at the rates of combustion in boilers of the Mercantile Marine the proportion of steam used for spraying to the water evaporated may be as low as 3 per cent. At higher rates of combustion it will generally be more. The American Liquid Fuel Board found that on an average it amounted to $4\frac{1}{2}$ per cent. in their shore tests, but probably it is seldom less than 5 per cent. under ordinary sea-going conditions. Taking the latter figure, we must therefore allow a discount of 7 lbs. off the 135 lbs. of water evaporated. This discount, however, does not end here, as this 7 lbs. of water which is wasted has to be made up by an expenditure of steam in the ship's evaporators, say another 11 lbs. It is true that this latter steam is recovered in the condensers, but it is not available for the auxiliary engines, or for propulsion of the ship. The nett result is, therefore, that, instead of getting 135 lbs. of steam for the propulsion of the ship, we have to write off 18 lbs., and the relative value of the oil and coal is reduced in the ratio of 117 to 100. The amount of steam required for heating the oil has been left out of consideration, as it is generally small, but if considered would reduce further the advantages of oil over coal.

This want of economy, together with the large increase of evaporating plant required to deal with the unavoidable waste of water, makes the steam-spraying system generally unsuitable for warships.

In the air-spraying system, though the amount of steam

required to drive the air-compressor is more than would be used actually to spray the oil if used directly, it is nevertheless recovered in the condenser, and we are not debited with a further consequent expenditure in the evaporators. The amount of steam required for the compressor will vary with the air-pressure. If air at about 100 lbs. is used, the amount of steam required by the air-compressor may amount to as much as 10 per cent. of the output of the boiler, and after writing off this expenditure the relative values of oil and coal become as 121 to 100. In the s.s. *Mariposa*, previously referred to, the air-compressor is estimated to be of 110 I.H.P., or about 5 per cent. of the power of the main engines, but as the compressor would, in all probability, not be so economical as the main engines, it may be estimated to use from 7 to 8 per cent. of the total evaporation, and after writing off this percentage on 135, the relative values of oil and coal become as 125 is to 100.

In the pressure system the quantity of steam required should be only about 6 per cent. of the quantity of oil pumped, and as this in turn will only be about 8 per cent. of the water evaporated, the quantity of steam required by the oil pump will be less than one-half per cent. of the total evaporation, and the relative value of oil and coal becomes about 134 to 100.

In the air-spraying system the weight of the air compressing machinery is considerable, and this is an objection to the system, particularly for warships, where weight is of great importance. In the *Mariposa* it is stated to be 9 tons, or about 4½ tons per 1000 H.P. of the main engines. In the pressure system, for a similar installation, the weight of the force pumps required would probably not exceed 1 ton. There are, of course, other additions in all systems, such as heating tanks, extra brickwork, etc., which are not required with coal.

63. *Furnace Arrangements.*—In boilers which are required to work with liquid fuel alone it is usual to remove the whole of the coal-burning fittings from the furnace, and to utilise the whole of the space for combustion.

If it is desired at any time to be able to revert immediately to coal, or if it is intended to burn oil and coal together, the fire-bars must, of course, be left in place. In the latter case, however, the reduced combustion space and the difficulty of supplying the air for the combustion of the oil in a satisfactory manner, makes the task of burning the oil smokelessly all the more difficult.

The brickwork, which varies with each type of boiler, serves two purposes, first to act as deflectors of the gases, and to assist in their mixing, and secondly, to supply a reservoir of heat to keep up the temperature of the furnace, and to assist combustion by regenerative action.

In the locomotive boilers referred to by Mr Urquhart in his paper read before the Institution of Mechanical Engineers in 1884, the brickwork took the form of a lining with arches connecting the side walls. The arches acted as deflectors of the gases, and prevented their direct impingement on the tube ends, some such arrangement having been found necessary to prevent leaky tubes. Any arrangement of arches, however, is generally unsuitable for marine boilers, especially of the water-tube type, as they would require to have a greater span than in the fire-box of a locomotive, and tend to collapse under the action of the heat. This instability of a brick arch in a water-tube boiler is referred to by the American Liquid Fuel Board in their account of the tests with the "Booth" burner, previously referred to. Accordingly, in water-tube boilers, the extent of the brick-work is generally limited to the side walls, and a brick lining to the ashpan. The brickwork in water-tube boilers therefore plays a very small part in deflecting the gases, and suitable baffles have to be arranged among the tubes. In

cylindrical boilers the brickwork may take the form of pillars, rings, chequerwork, or sometimes a hanging bridge is formed at the throat of the furnace to protect the joint of the furnace and tube plate. In the latter case the bricks are often bolted up, and, as a rule, require frequent replacement.

Marine Boiler burning Liquid Fuel and fitted with Ellis & Eaves' induced draught.

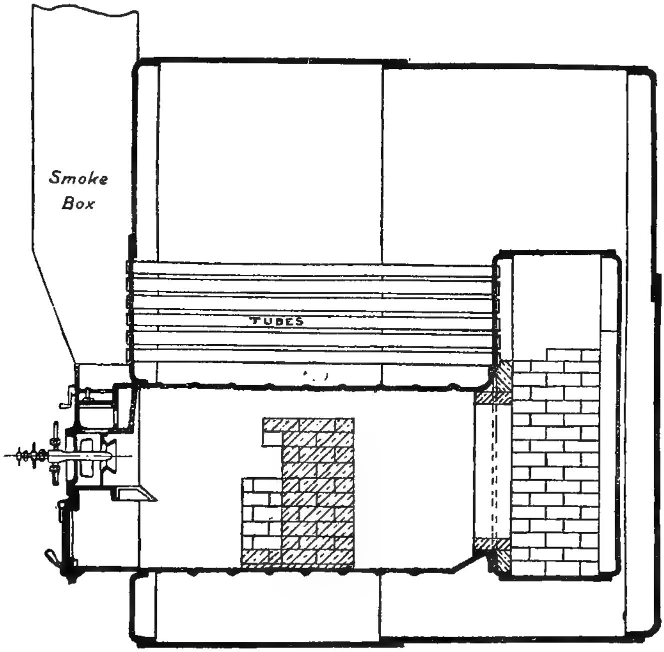


Fig. 49.

As regards air supply, no general rule can be laid down, since the conditions will vary with each type of boiler. In cylindrical boilers, where all the air must be admitted through the front of the furnace, provision should be made to deflect the air supply against the stream of oil or oil vapour. In water-tube boilers it is possible in many cases to introduce air at the back of the furnace, which is advantageous, as the air and oil streams move in opposite directions, and

Marine Boiler burning Liquid Fuel and fitted with Ellis & Eaves' Induced Draught with Heated Air.

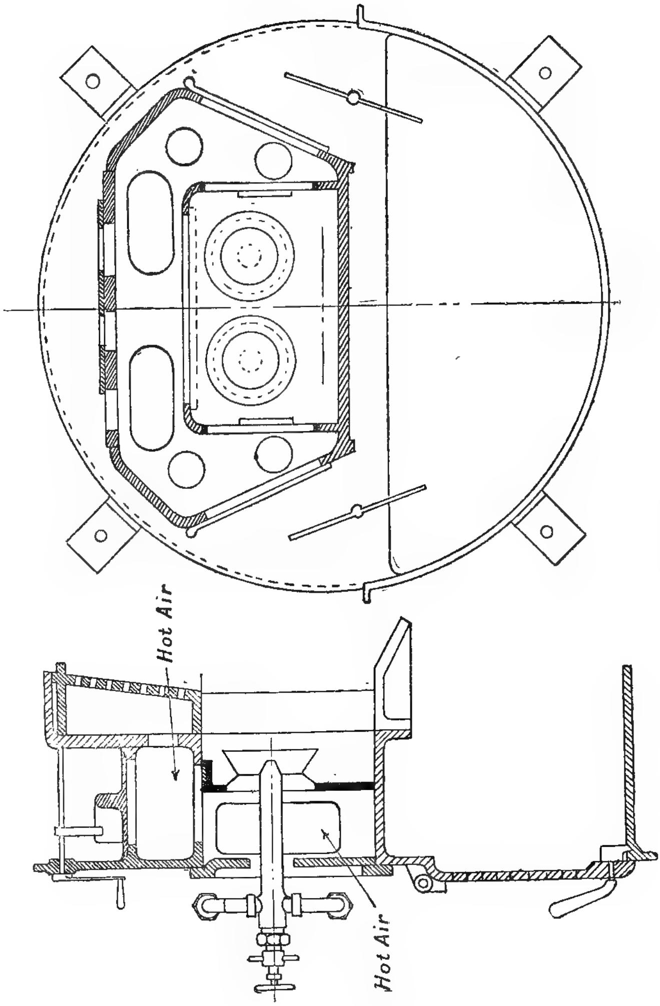


Fig. 50.

therefore have a greater opportunity of becoming intimately mixed than when moving side by side.

These points, as regards brickwork and heated air supply, as applied to cylindrical boilers, are illustrated by the arrangements shown in Figs. 49 and 50. The furnace door aperture is fitted with two burners of the Rusden & Eeles type. The hot air enters the casing of the furnace front, and a part of it is drawn through the conical inlets shown round the burner nozzles. The remaining air, which forms the main part, enters the ashpit space through the butterfly valves. The main air is deflected upwards by the brick pillars arranged about 3 ft. inside the furnace (Fig. 49). A brick ring is built to protect the joint at the throat of the furnace, and the back of the combustion-chamber (common to two furnaces) is lined with brickwork to the height shown, a buttress wall being fitted between the two furnaces. A similar arrangement was fitted to one boiler of the s.s. *Kensington*, and ran satisfactorily for several trips, but the fittings were subsequently removed for considerations connected with the supply and price of the oil fuel. In a three days' test, made at the works of Messrs J. Brown and Co., Sheffield, on a marine boiler having a heating surface of 1,200 sq. ft., the mean actual evaporation was 11,275 lbs. of water per hour, and the equivalent evaporation from and at 212° Fahr. per lb. of oil was 15.09. The calorific value of the oil was equivalent to 19.63 lbs. of water from and at 212° Fahr., and the efficiency of the boiler was therefore nearly 77 per cent. At a previous test an evaporation of 16.1 lbs. of water from and at 212° Fahr. was obtained, giving a boiler efficiency of 84 per cent. No doubt part of the excellence of these results was due to the heating of the air, which entered the furnace at a temperature of about 250° Fahr. The gain in efficiency due to heating the air was noticed by Mr Urquhart, and is referred to in his paper previously quoted.

Fig. 51 refers to the furnace arrangement in the s.s. *Tebe*, fitted with Körting sprayers and Howden's system of

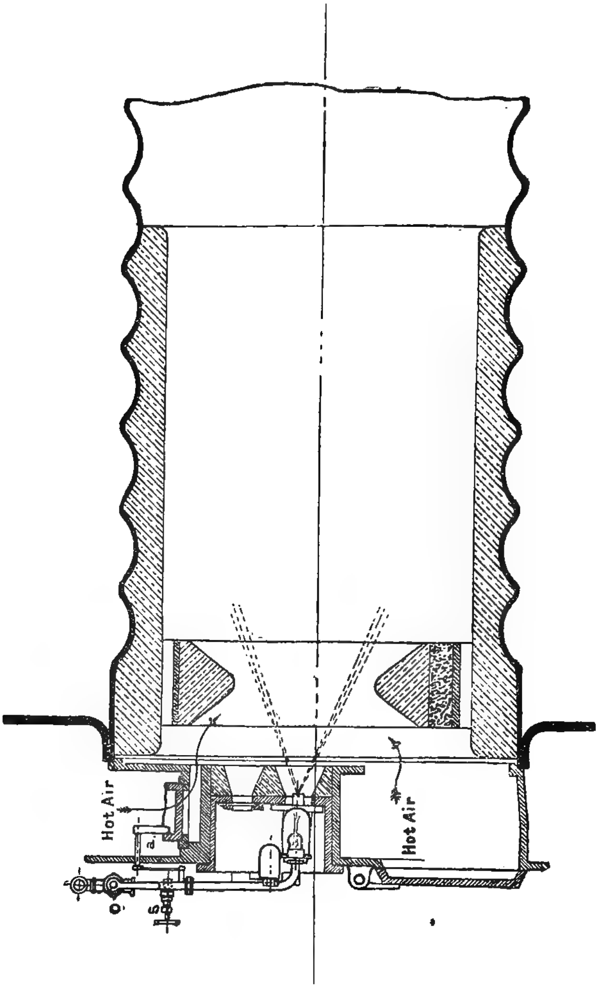


Fig. 51.

ARRANGEMENT OF FURNACE, S.S. *Tebe*.

forced draught. An account of this installation has been published in the *Rivista Marittima* (March 1904).

The furnaces are here lined with fire-brick for about half their length, and there is a brick ring just inside the furnace

through which the air has to pass. The report states that the results of experiments made in relation to power and consumption of fuel showed from 1.004 to 1.087 lbs. of fuel per I.H.P. per hour. The consumption of coal in the ship is stated never to have been less than 1.5 lbs. per I.H.P. per hour.

An example of a recent installation is that fitted in the s.s. *Goldmouth* by the Wallsend Slipway & Engineering Company, who have equipped a large number of steamers for oil burning (Fig. 52). This installation is on the Flannery-Boyd system of settling tanks, and the burners are of the Rusden & Eeles and of the Körting type, the former being fitted to two boilers and the latter to one. In the Flannery-Boyd system two liquid fuel settling tanks of large capacity are placed in the ship at some distance above the boilers. The tanks are made of sufficient size to contain half a day's supply, and are fitted with heating coils, draining arrangements, and thermometers, to enable the fuel to be heated to the desired temperature, so that any water contained therein may separate freely. The water then settles to the bottom of the tank, and can be drained off. The tanks are fitted with overflow pipes to return to the fuel space in the ship's double-bottoms or ballast compartments; they have also open-ended pipes opening above the level of the upper deck. From these tanks the oil runs by gravity through suitable oil-strainers to the steam-burners, and to the pressure-pumps required by the Körting system. The general arrangement of oil pipes is indicated in Fig. 52, and for clearness the steam system has been omitted; the boiler with the Körting sprayers is that on the left hand side.

The separation of water from the oil fuel is very necessary, as even a small percentage of water will cause a disagreeable pulsating effect on the working of the burners, while a moderate quantity will cause the flame to go out com-

pletely. If this should happen the oil should be shut off for a short time, the steam being left on to blow through the oil vapour which may have collected in the furnace. If this precaution is neglected and a torch applied, a

OIL-BURNING ARRANGEMENT ON THE KÖRTING AND THE RUSDEN & EELES SYSTEM.

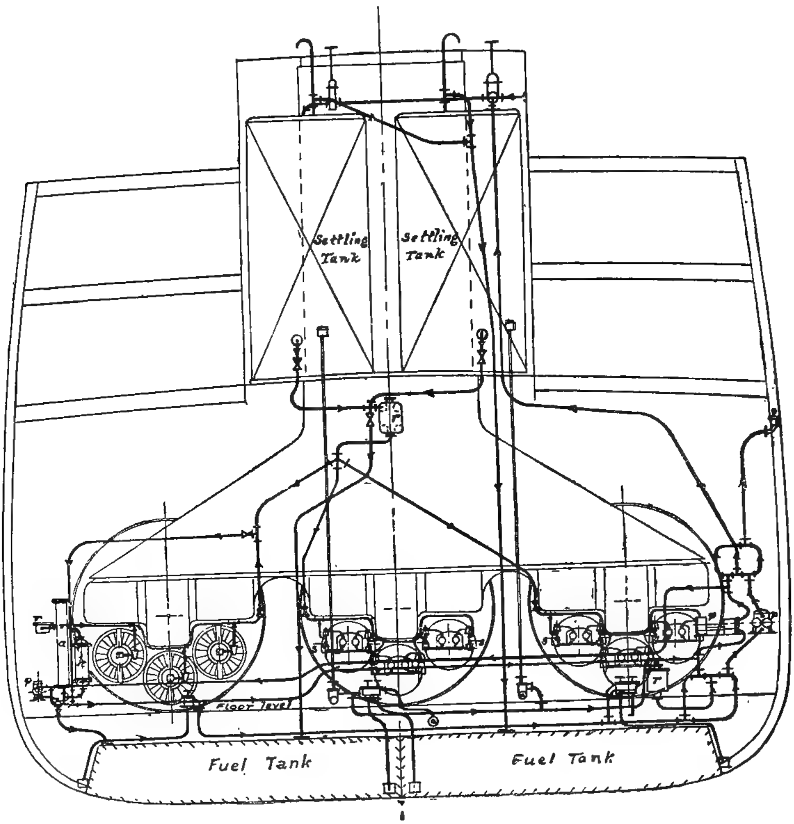


Fig. 52.

dangerous explosion may occur in the furnace. When the action of the burner is intermittent, due to the presence of water, slight explosions may be frequent, causing the flame to flash back into the stokehold.

64. *Mixed Fuel Burning.*—At the present time the number of ports where fuel oil can be obtained is very small compared with coaling ports, and while it is practicable for merchant steamers trading on a fixed route between "oiling" ports to burn oil only, it is necessary for vessels whose itinerary may be varied, especially war vessels, to be able to burn oil and coal alternatively, or in combination. It is obviously impossible with elaborate brickwork arrangements in the furnace to revert readily to coal burning, and therefore when this is desired it is usual to retain the fire-bars and cover them with broken fire-bricks or clinker, on to which the oil is sprayed when burnt alone, or if burnt in conjunction with coal, the spray is directed over the coal fire. In the former system the difficulty of burning at high rates of combustion is increased, owing to the reduced combustion space; in the latter system the difficulty is still further increased, owing to the fact that coal and oil entail different systems of air supply, requiring careful arrangement, but even then their manipulation necessitates more skill and attention than the "all-oil" system.

The advantages of mixed fuel burning scarcely apply to ships of the mercantile marine, and the disadvantages of increased cost of the installation, the added complication, together with the fact that practically no saving in *personnel* is possible, make it tolerably certain that merchant vessels will continue to burn either coal only or oil only, as at present. For war vessels, however, certain tactical advantages arise from the use of the combined fuels, which may be thus briefly stated:—

(1) The oil fuel being carried in the double bottoms, in addition to the full stowage of the bunkers, gives the ship a larger radius of action.

(2) When the fires get dirty the full speed may be maintained by turning on the oil supply to the furnaces.

(3) Maintenance of full speed is also assured when the

coal is worked back in the bunkers, and it becomes difficult to supply the furnaces with coal at a rate sufficient to maintain the full speed. This state of affairs may also arise in action when it may be undesirable or impossible to spare the men necessary for trimming the coal.

(4) Oil alone may be used at slow speeds, or in harbour, thus releasing a certain number of men from the duties of stoking, who may be usefully employed in other work.

(5) The furnaces are available immediately for coal only should the supply of oil fail.

The advantages of the all-oil system are greater even than those of mixed fuel, but, until the world's production of liquid fuel is increased very largely, oil alone is not likely to be adopted for war vessels except in special cases.

65. *Oil Fuel for Naval Purposes.*—In recent years much attention has been devoted to the burning of liquid fuel by the navies of several nations. The Italian navy has adopted liquid fuel for many of its torpedo-boats, while the armoured ships *Sardegna*, *Sicilia*, *Re Umberto*, *Lepanto*, etc., are fitted for burning mixed fuel. In the French navy several ships are arranged to carry a limited quantity of oil fuel (about 80 tons) in their double bottoms, among them being the *d'Entrecasteaux*, *Montcalm*, *Kléber*, *Guichen*, *Chateâurenault*, *Gloire*, etc. Some of the torpedo-boats of the Russian navy and the battleship *Rostislav* of the Black Sea Fleet use oil fuel alone, while several other large ships are arranged for mixed fuel burning. In the German navy also many of the battleships and armoured cruisers are arranged for burning mixed fuel. The most important and most recent experiments are, however, those carried out by the Admiralties of Great Britain and the United States.

The British experiments commenced in the torpedo-boat destroyer *Surly*, fitted with Normand boilers, but these experiments not giving at first very good results, extended

shore trials were made, so that the conditions of working could be more closely observed, and alterations carried out more readily than in the confined space of the stokehold of a torpedo-boat destroyer. These tests were carried out in various types of boilers, including Normand, Belleville, and cylindrical, at Devonport and Portsmouth, with results so promising that the battleships *Mars* and *Hannibal* had half the cylindrical type boilers fitted to burn oil in conjunction with coal. Subsequently, the cruiser *Bedford* was fitted with part of her installation of Belleville boilers to burn oil and coal together. All these ships were fitted with steam-spraying burners, and the results of trials at sea showed that it is possible in each case to obtain smokeless combustion when burning oil and coal together, at the maximum power of the boiler. In the meantime, the shore experiments were continued with a view of determining a satisfactory type of pressure-spraying burner, and as the result of these latter experiments the torpedo-boat destroyer *Spiteful* was fitted with a complete equipment of burners operating on the pressure system, the structure of the vessel being modified to enable the necessary quantity of oil to be carried. Comparative trials have been run recently between the *Spiteful* burning oil, and the *Peterel*, a sister ship, burning coal, with results, it is stated, entirely favourable to the former. As the manipulation of liquid fuel fittings requires much skill in order to ensure the best results, several boilers of different types are being erected at Portsmouth, in order that the various problems connected with liquid fuel burning may be more effectively studied and instruction given to the engine-room ratings of the Fleet. The use of liquid fuel in conjunction with coal is being extended to other ships. In the battleship *Prince George* some of the boilers have recently been fitted to burn oil in conjunction with coal, the burners being of the pressure type, and it is stated

that the cruiser *Bedford* is also to have her oil-burning system extended. In the former vessel, one of the ship's dynamos is being worked by an oil engine using the same fuel as that burnt in the boilers.

The Report of the American Liquid Fuel Board has been previously referred to, and it remains to indicate briefly some of their principal conclusions. They find that no difficulty should be experienced by intelligent stokers in burning oil in a uniform manner. That the additional evaporating plant is practically the main objection to the use of steam as a spraying medium. That with highly heated compressed air, the combustion can be forced to a greater extent than with steam. That special provision should be made for removing water from the oil. That little difference is found in the evaporative efficiency of different oil fuels. That the great benefit of heating the air required for combustion cannot be doubted. That the oil should be heated before it is supplied to the burners. That there should be a reserve of burners which should be capable of easy examination and renewal. That there should be special provision for straining the oil. That the simpler the furnace the greater its efficiency, and that in many cases brick arches only tend to reduce the volume of space necessary for effecting complete combustion. That the design of an oil-burning installation will depend primarily on the character of the fittings and auxiliaries; the form of the burner, so long as it is constructed in accordance with well-known principles and all its parts are accessible for overhauling, will play a very small part in extending the use of crude petroleum. That under severe forced draught conditions, and with water-tube boilers, the solution of the smoke question is nearly as remote as ever. That there should be no attempt made to use oil as auxiliary and supplementary to coal, as such an installation is sure to prove unsatisfactory, and the solution

of the oil-fuel problem is only delayed by any attempt to inject a limited supply of oil fuel over a bed of incandescent coal.

In view of the success attending the British experiments in burning oil and coal together, the last quoted conclusion, which, so far as can be gathered from the Report, is not supported by experimental evidence, appears to be somewhat premature.

It is doubtful also, whether for a naval vessel an installation which requires twenty-four hours to revert to coal burning can be regarded as satisfactory. It is not difficult to imagine circumstances under which a warship would require to utilise the tactical advantages which oil fuel gives till the last drop had been burnt, and to go on steaming at full power immediately on coal alone. In such a case the laying off of a portion of the boilers in order that the furnace fittings might be replaced would detract very seriously from the efficiency of the ship as a fighting machine.

The other conclusions quoted above are generally in accord with experimental evidence, and can be readily conceded, except that it is to be noted that the smoke nuisance has been successfully overcome in the British naval vessels burning liquid fuel.

The oil-fuel problem for naval vessels admits of the following solutions :—

(1) To burn oil only, in all the boilers.

(2) To burn oil only in part of the installation and coal only in the remainder, the furnaces for burning oil being especially constructed for it.

(3) To burn either coal only, oil only, or both together, in all or part of the installation, the furnaces being arranged so that either plan can be carried out without making any change in the fittings.

In the present state of the world's supply of liquid fuel the first solution is obviously impracticable of general

application, but in certain classes of vessels, such as torpedo-boat destroyers, it may become necessary to adopt this solution on account of the difficulty of arranging satisfactorily for an adequate storage on board of two fuels. In such a case the operations of these vessels would naturally have to be confined within their radius of action from a base from which supplies of oil fuel are procurable.

The second solution requires that ships so fitted shall be similarly limited in their operations, or that a risk shall be run of part of the boilers being rendered for a time inoperative in the event of the supply of oil failing.

The third solution appears to be the most reasonable, if the requirements of satisfactory combustion can be met, as the ship can make use of the advantages of oil fuel, while supplies can be obtained and can still maintain full power with coal only when the oil fuel is exhausted.

66. *Liquid Fuel for Internal Combustion Engines.* — One other aspect of the use of liquid fuel for marine purposes remains to be considered, namely, in internal combustion engines. The oil engine, as a practical working machine, is less than thirty years old, and in recent years great strides have been made in the application of this form of motive power, principally for stationary purposes, and more recently still for boats, small yachts, submarine vessels, and as auxiliary engines for ships.

Broadly speaking, we may divide oil motors into three classes, according to the class of fuel used, that is to say, petroleum spirit motors, motors using refined oil, and motors capable of using the residual oils, such as are burnt in a steam boiler.

Petroleum spirit motors have been used in submarine vessels and in small boats, but its general use in sea-going ships is rendered unlikely for two principal reasons, the first being its comparatively small supply and high price, and

the second the danger attendant on its use, on account of its inflammable properties.

These objections apply, though to a less degree, to the use of refined oils, which, if used to any extent, would be required to be stowed on board in bulk, special precautions being taken against leakage into other compartments, and the collection of inflammable vapour.

The third class of engines, therefore, are those to which attention should be most directed in their application to marine work, on account of their using the cheapest and safest quality of fuel.

One great advantage, which internal combustion engines possess over steam engines is economy of fuel. In a land installation of steam engines, with all available devices for increased economy, the indicated work of the engine may amount to 15 or 16 per cent. of the heat energy in the coal burnt. Such an economy, though not impossible of realisation in marine work, involves considerable sacrifices in the matters of weight and space required for the installation, which would tend to neutralise in other directions the gain in economy.

Accordingly, we rarely find in merchant vessels installations giving more than 12 or 13 per cent. of the heat value of the coal in indicated work, while in naval vessels, where the conditions are not so favourable to economy, the percentage does not exceed 11, and in vessels such as torpedo-boats and torpedo-boat destroyers it may be as low as 7 per cent.

Oil engines, on the other hand, give thermal efficiencies of from 20 to 40 per cent., according to the size and the type of the engine, so that it would be possible to give a ship the same radius of action if driven by oil engines, with only about one-third to one-fifth the quantity of fuel required by steam engines of the same power. Up to the present, however, oil engines have only been applied to the pro-

pulsion of vessels of small size, and the following difficulties stand in the way of their immediate application as motive power for large vessels, viz.—those of handling, reversing, regulation of speed, and the necessary experience with large sizes.

The difficulties above referred to will be appreciated when it is remembered that the purposes for which oil engines have mostly been applied require a constant speed in one direction only, so that the transition to the conditions of a marine engine, which requires to be stopped and started in either direction, will not be made without the exercise of considerable thought and inventive skill. In small boats the difficulty has been obviated by fitting either feathering screws, or by clutch and gearing, the engine running continuously in one direction at a nearly constant speed. These devices, however, it will be generally admitted, are not such as can be employed in the transmission of large powers. In the Bertheau engine, which has been fitted to boats in this country by Messrs. Thornycroft, the problem of reversing has been solved satisfactorily. The engine is operated at starting by compressed gas from a reservoir, which is kept charged, while the engine is running, by a portion of the products of combustion flowing out of the cylinder during the explosion stroke through a non-return valve into the reservoir. At starting, the cylinders take the compressed gas at the beginning of every downward stroke, but when once started all the cylinders but one are made to operate on the usual four-stroke cycle till the ignition is regular, and when this is obtained the remaining cylinder is made to work in the same manner. The various operations are effected by an ingenious arrangement of cams, and the results of trials have shown that an engine working on this principle is as handy and as reliable as a steam engine. The disadvantages of the system for large powers are the comparatively large size

of gas reservoirs and the possibilities of losing the pressure in them.

The difficulty of regulation of speed will disappear probably with experience, since owing to land requirements being for constant speed engines little attention has been given to this point.

In the matter of size, progress, no doubt, will be slow. The largest power in a single oil engine cylinder constructed at the present time is 160 brake-horse-power, and so far as is known this size has only been attained in the Diesel and Hornsby engines, both of which types can use liquid fuel. By multiplication of cylinders much larger powers will of course be obtained, and so long as oil engines are made to work on the four-stroke cycle, that is to say, giving only one working stroke per cylinder every two revolutions, probably not less than four cylinders will be required on one shaft to ensure readiness of starting and a fairly uniform turning moment. Assuming, therefore, that the difficulties referred to can be overcome satisfactorily in large sizes, there are great possibilities for the use of the oil engine for propulsion. Some saving in weight may be expected over an ordinary steam installation, and considerable saving in space owing to absence of boilers. There will also be a large reduction in the weight of fuel carried, and a very large saving in *personnel*; while owing to the higher efficiency of the oil engine, the cost of fuel will not be greater, if a cheap fuel oil is procurable.

When used as auxiliary engines for ships the difficulties are not so pronounced as when used for propulsion, and they consist principally in reducing the weight of the engine and the space occupied; moreover, the advantages in economy are greater since the steam consumption of the auxiliary steam engines is increased by steam-pipe and other losses, which losses have no counterpart in the oil engine.

As an instance of this, it has been shown by trial of a

Hornsby oil engine coupled to a dynamo that 12 cwts. of liquid fuel consumed in the engine was sufficient to light the ship on which the engine was fitted for 24 hours, whereas a similar electrical output from a steam-driven dynamo required the expenditure of 3½ tons of coal per day.

There appears to be a tendency, on warships at least, to extend the application of electrical power for auxiliary work, and where only a limited quantity of liquid fuel can be carried the adoption of some form of oil engine for dynamo driving appears to be more economical than burning the liquid fuel under the boilers. Further, the oil engine with electrical power enables steam to be dispensed with in harbour, so that boiler cleaning and repairs and the making good of defective pipe joints can be the more readily effected. In this respect the oil engine becomes a valuable auxiliary to the boiler, enabling it to be kept ready for immediate service.

CHAPTER VI.

§ 1. PRODUCTION OF HEAT.

67. *Total Efficiency of a Boiler.—Sub-division into Furnace Efficiency and Utilisation of Heat.*—The efficiency of a boiler is determined from the results of trials with a fuel of known calorific value. If, for example, we take the case of the old rectangular boiler which evaporated 8.5 lbs. of water per pound of coal, at a pressure of 28.4 lbs., we find that the thermal units expended were 9,680, assuming that the feed-water was at a temperature of 50° Fahr. and that the dryness fraction of the steam is 1. The calorific value of Anzin coal being equal to 16,560 thermal units, the efficiency of the boiler is thus 58.4 per cent. With the modern boiler evaporating 9.6 lbs. of water at a pressure of 114 lbs., the efficiency under the same conditions would be 67 per cent. Taking into account the fact that steam produced by a cylindrical boiler contains about 4 per cent. of water, the actual efficiency of tubulous boilers may be stated as being about 65 per cent. For any boiler the efficiency can be determined by an evaporative test similar to the tests made on coals purchased for the French Navy.

The efficiency of a boiler is the product of two distinct factors, the first expressing the degree of completeness of combustion in the furnace and smoke-box, the second being the quantity of heat transmitted to the water.

The combustion in a boiler, neglecting the coal lost with the ashes, can never be as complete as in the pure oxygen of Berthelot and Vieille's bomb calorimeter, because the flame

is always extinguished too soon by being prematurely cooled down. It is generally admitted that a boiler can never utilise more than 14,000 thermal units instead of 16,560 thermal units, which gives a maximum efficiency of 85 per cent. Upon this point there is only the analysis of the flue gases to rely upon. It is likely that in certain tubulous boilers with very small combustion-chambers the foregoing figure is never reached, while in others it may be exceeded.

The proportion of heat actually utilised can be estimated when the temperature of the furnace and that of the gases at the base of the funnel is known. If, for example, the furnace temperature is 2,912° Fahr. (which is a maximum value), and the temperature of the outgoing gases is 572° Fahr. (which is a minimum value), when the temperature of water and steam is 392° Fahr., and the atmosphere 60° Fahr.; the loss of heat is then $\frac{572-60}{2,912-60}$ or 18 per cent., neglecting the latent heat of the steam contained in the gases.

The funnel temperature is often as high as 662° Fahr., 752° Fahr., or even higher. The loss of heat in the funnel may be increased in two directions. Firstly, by a high temperature in the funnel, which may be due to an inefficient boiler or incomplete combustion, and secondly, by a lowering of the furnace temperature due to an excess of air in the furnace.

To the loss by the hot gases passing out of the funnel must be added that due to radiation and conduction, which is difficult to estimate, but which may be taken as about 5 per cent. on a well-lagged tubular boiler; finally, there is the heat carried away by the cinders falling into the ashpit.

The total heat transmitted to the water may be estimated at 75 per cent.

Combining the two efficiencies of 85 per cent. and 75 per cent. gives a value for the total efficiency of very nearly 65 per

cent., which was previously mentioned as that of the tubular boiler used in the coal-tests.

In tubulous boilers the efficiency of the furnace varies considerably according to the different types. On the other hand, the heat utilised has sometimes been very small, and it is no uncommon thing for the base of the funnel to become red hot. Great progress has been made in each of these two directions, but sufficient data are not yet to hand to enable a universal rule to be established. The following figures show the utilisation of heat in a Mosher boiler, experimented upon in America :—

Heat utilised in evaporating the water	76·0
Heat lost in the funnel	13·0
Heat lost in radiation	9·1
Heat lost in the cinders and by the evaporation of the water in the ashpan	1·9
Total heat of combustion	100·0

Radiation is greater and more difficult to overcome in tubulous than in tubular boilers.

68. *Quantity of Air required for the Complete Combustion of Coal.—Loss of Heat due to Excess of Air.*—The quantity of air theoretically necessary for the complete combustion of 1 lb. of coal is easily calculated when the chemical composition of the coal is known. Let us assume that this coal contains 85 per cent. of pure carbon and 5 per cent. of hydrogen, the remaining parts being made up of other constituents, including oxygen. Atmospheric air containing 0.0187 lb. of oxygen per cubic foot, 142.6 cubic feet of air will be required for the complete combustion of 1 lb. of carbon, and 427.8 cubic feet for the combustion of 1 lb. of hydrogen. The coal we are dealing with would then require 121.1 cubic feet of air to consume the carbon and 21.39 cubic feet for the hydrogen, making in all 142.5 cubic feet or 11.15 lbs. of air per pound of coal burnt.

The actual burning of the coal in the grates, which will be

described later, requires the presence of a considerably larger quantity of air than is given by the preceding considerations, though the precise amount required in excess is unknown. Some experiments made in 1873 at Indret by M. Joessel on the old type of boiler with natural draught gave him the following results :—

Coal burnt per square foot of grate per hour . . . lbs.	15·2	18·2	21·1	25·8
Velocity of air through ashpit door . . . feet per sec.	14·6	14·6	13·3	13
Volume of air per pound of coal cub. ft.	368·5	307·6	240·3	193·8
Ratio of air supplied to that theoretically necessary . . .	2·6	2·2	1·7	1·4

Another series of trials, made in 1877 by the Author on board the *Résolue* with a cylindrical tubular boiler, gave some results which had a wider range because they were made both with natural and forced draught. The first trial is with natural draught, the others are with forced draught produced by blowing jets of air into the funnel. The velocity of the air in the furnaces is deduced from observations made in different parts of the only door leading into the stokehold.

Coal per square foot of grate . . lbs.	19·7	28·7	32·6	26·7	30·4
Inches of water in the smoke-box . . in.	0·32	0·51	0·58	0·63	0·69
The speed of air in the ashpan . feet per sec.	10·5	12·7	13·2	14·2	14·7
Volume of air per pound of coal . . cub. ft.	363·6	301·1	281·9	262·7	248·3
Ratio of air supplied to that theoretically necessary	2·5	2·1	2·0	1·8	1·7

According to these figures the ratio of the quantity of air actually supplied to the amount theoretically necessary is, in round numbers, 2.5 with natural draught and a combustion of 20.5 lbs., 2 with forced draught and a combustion of 30.75 lbs., and 1.75 with forced draught and a combustion of 41 lbs.

Much higher rates of combustion have been obtained since these experiments, but no observations with regard to the actual consumption of air have been made.

It has long been known that an excess of air in the furnaces is necessary to ensure complete combustion. Considerable advantage has been found in admitting air above the grates. These currents of air, which are admitted partly through the fire-doors and partly through the furnace bridges slightly diminish the draught above the grate, and consequently the passage of air through the coal and the amount of coal burnt. But by ensuring more complete combustion, the power of the boiler is appreciably increased. The velocity of air admitted to the furnace, and which has not to pass up through the fire, easily reaches 40 to 50 ft. with natural draught, so that only very small openings above the grate are necessary.

In cylindrical return-tube boilers one-third of the total quantity of air may with advantage be admitted above the grate, an amount which is equal to one-half of the volume of air passing through the grates.

The presence of air in excess of that necessary to support complete combustion and which passes up the funnel carries with it a large amount of heat. The specific heat of the gases at constant pressure being about 0.23, each cubic foot of air admitted in excess per pound of coal burnt and passing out at 572° Fahr. carries with it:—

(1) $1.3 \times (572^\circ - 32^\circ) \times 0.23 = 161$ B.T.U.

or more than 1 per cent. of the total heat produced.

The combustion of 1 lb. of coal by 19.5 lbs. of air

produces 20.5 lbs. of gas with a specific heat of 0.23. The temperature of the hot gases is then about 3,000° if the quantity of heat produced is equal to 14,040 B.T.U. No account is here taken of the fall in temperature of the gases due to the abstraction required for the production of steam. The 20.5 lbs. of gas passing out through the funnel at a temperature of 572° carries off 2,650 B.T.U., or 18.8 per cent. of the heat produced, which agrees very closely with the figure given in paragraph 67 obtained by another method of calculation.

69. *Combustion of Coal.—Chemical Reactions.—Temperature of the Flame.*—Let us now consider what takes place upon a grate covered by a fire of uniform thickness. The coal burnt per hour and per square foot depends upon the amount of air which passes through the fire and the depth of coal on the grate.

For any given thickness of fire the rate of combustion increases with the draught, and experiment has shown that within the limits of natural draught it is nearly proportional to the volume of air supplied. Combustion would then be complete, and the composition of the flue gases would be constant.

For any given quantity of air the rate of combustion increases with the thickness of the fire until the whole of the oxygen in the air is combined with the carbon in the coal.

Passing now to the consideration of forced draught, and assuming that it is proposed to burn a certain quantity of coal per hour, the usual conditions of stoking are as follows.

The thickness of the fire is in practice fixed within certain well-defined limits, because it cannot exceed the maximum thickness beyond which the grate will become choked and the combustion incomplete, nor can it fall below a certain

limit depending on the amount of coal to be burnt. As complete combustion depends on the quantity of air passing through the furnace, directly the thickness of coal on the grate is in excess of the maximum quantity beyond which combustion becomes incomplete, choking of the grate rapidly takes place. A reduction in the supply of air is thus coincident with an excess of the coal supply. No exact measurements have been made of the thickness of fire giving a maximum combustion at various draughts. In practice 6 ins. to 8 ins. mean thickness is never exceeded in ships when burning from 20 to 40 lbs. With higher rates of forcing a thickness of 8 ins. and above may be allowed, but good stokers usually prefer to keep a thin fire for the reasons given above.

Combustion takes place in the following manner. The lower surface of the coal receives the current of air and very active combustion takes place, resulting in the formation of carbonic acid; the temperature reaches at least 2,700° Fahr. The flame is white-red in colour. As the current of gas rises it contains a constantly increasing proportion of carbonic acid, which is decomposed by contact with the incandescent fuel, thus:—

$$CO_2 + C = 2\,CO. \tag{2}$$

Combustion continues at the expense of the oxygen still contained in the gas, but producing carbon monoxide as soon as the oxygen ceases to be in excess. The temperature corresponding to these reactions is much lower than the preceding one. As the current rises, the air, which is still being gradually deprived of its oxygen, encounters the green or newly-charged coal; here the volatile hydro-carbons are being given off in long thread-like streams of gas and the temperature falls yet lower. On the upper surface of the coal the movement of the flames increases the contact between the remaining oxygen and the combustible gases,

carbon monoxide and the hydro-carbons; at the same time a new influx of air through the apertures in the fire-doors causes a great increase in the intensity of combustion.

In order to ensure good combustion a large combustion-chamber is needed; this is met with upon cylindrical return-tube boilers, though even here the dense volume of smoke given off when the furnaces are freshly charged, and the deposit of soot in the tubes, show that the combustion is far from perfect. On boilers with the tubes leading direct out of the furnace the conditions are even worse. Upon the earlier Belleville and Niclausse boilers the combustion-chamber was reduced to practically nothing, and consequently a large excess of air, such as is furnished by forced draught, was absolutely necessary. Upon recent boilers, with accelerated circulation, the height of the furnaces has been much increased in order to give ample space for the proper mixing of the gases, and the combustion-chambers have been lengthened.

70. *Combustion of Petroleum.*—If the principles enunciated above with reference to the combustion of coal be applied to the combustion of petroleum it will be found that a pound of the latter composed of .85 lb. of carbon, .14 lb. of hydrogen, and .01 lb. of other constituents requires the following proportions of air.

121·2 cubic feet of air for the carbon
59·9 cubic feet of air for the hydrogen

181·1 cubic feet in all.

If the mixing of the combustible and the oxygen be very complete, the excess of air necessary for perfect combustion may be reduced. By adding an excess of air in the proportion of about 1.3 to 1, that is to say, allowing 231 cub. ft. or 18.7 lbs. of air per pound of petroleum, complete combustion can be obtained with a

consequent disappearance of smoke, a result which, in the case of coal, could not have been secured without a considerable excess of air.

Under these circumstances, the theoretical temperature of the flame, deducting the heat turned to account before the completion of combustion, is :—

(3) $$\frac{19,800}{(18.7 + 1) \times 0.23} = 4,368° \text{ Fahr.}$$

If the gases could be passed out, as in the case of coal, at a temperature of 572° Fahr. the loss of heat through the funnel, assuming an atmospheric temperature of 60° Fahr., would then be—

$$\frac{572-60}{4,368-60} = 11.6 \text{ per cent.}$$

only of the total heat, which represents an increase in the proportion of heat utilised as compared with coal, of

$$18-11.6=6.4 \text{ per cent.}$$

Moreover, there is a further gain of 1.9 per cent., which in the case of coal would have been lost in the ashes or in the cooling of the ashpits. The heat turned to account, estimated above as 75 per cent., would, in the case of petroleum, amount theoretically to

(4) $$.75+.064+.019=.833 \text{ or } 83.3 \text{ per cent.}$$

This figure would be the total thermal efficiency if, as has been assumed, combustion were complete, and the efficiency of combustion equal to unity. The relative heating value of petroleum, as compared with coal, would thus be increased, by good combustion and good utilisation of heat in the ratio of :—

(5) $$\mu = \frac{0.833}{0.65} = 1.28$$

becoming thus—

(6) $$\rho = 1.20 \times 1.28 = 1.53.$$

It has, however, been found by experiment that the value of ρ only equals 1.33 and that of μ equals 1.11.

That is to say the result of experiment is, as pointed out in the preceding chapter, that the relative heating values of petroleum and coal are nearly proportional to their calorific values.

The value 1.28 obtained for μ is undoubtedly exaggerated, owing to the small total thermal efficiency of 65 per cent. which has been taken for heating by coal alone. Nevertheless, the decrease in μ, even supposing it to be less than 17 per cent., proves the impossibility of attaining the perfect combustion and utilisation of heat assumed. The causes of this loss are due to the nature of the petroleum flame.

In the first place, the flame of petroleum having only a feeble radiating power compared with that of coal, the evaporative value of the direct heating surface of coal-fired boilers is lost. To make up this loss by conduction, it would be necessary to increase the heating surfaces of the tubes to an inadmissible extent.

In the second place, the petroleum flame is of considerable length, unless it is shortened by a suitable arrangement of the burners and by heating the oil previous to injection; combustion only becomes complete after the gases have passed some way across the tubes towards the funnel. There is thus a risk of early extinction of the flame followed by relighting in the funnel. The following are the causes of this:—

On leaving the burners a series of complicated chemical reactions takes place during which heat is absorbed and not given out. The jet remains cold for a certain length. A little further on combustion commences, the jet becoming highly luminous, due to the particles of incandescent carbon. Combustion, more or less rapid, according to the completeness of the mixture of the gases and the air, requires a

certain time, t, for its completion, during which the jet moving at a high speed, U, traverses a length

$$(7) \qquad L = Ut,$$

which may be several feet. If the course of the hot gases through the boiler is very short they may have reached the up-take before combustion is complete, in which case the efficiency of combustion or the utilisation of heat is prejudicially affected.

Owing to the length of the flame and the absence of radiating power a long furnace is necessary, and considerable length of travel should be allowed to the hot gases.

71. *Combustion of Petroleum and Coal in Mixed Firing.*—In mixed firing the conditions of combustion for each of the two fuels are modified by the presence of the other. The combustion efficiency of the coal is markedly increased, and the utilisation of the heat in the case of petroleum is better because the quantity burnt is much less.

The principal improvement is due to the more intimate mixing of the flames from the coal by the jets of atomised petroleum. Though the combustion upon the grate may be incomplete, the combustion in the furnace is nearly perfect, however small the quantity of oxygen in excess of that theoretically necessary, and however restricted the grate area. Moreover, the excess of air which passes through the interstices of the grate and of the coal is utilised for the combustion, either of the hydrogen and of the carbon monoxide of the coal, or of the atomised petroleum. In this way, by regulating the amount of air passing through the ashpit, that entire absence of smoke, which is the best index of complete combustion, can be ensured.

If the proportion of petroleum to coal is low, say one-fifth, the proportionate heating value of the petroleum, as compared with the coal, is very high. Taking 5 lbs. of coal,

each developing in the furnace 16,560 B.T.U. with perfect combustion, instead of 14,000 B.T.U. with imperfect combustion, 12,800 B.T.U. are gained; at the same time, the pound of petroleum which obtains all the oxygen necessary for its combustion from the excess of air which accompanies the 5 lbs. of coal, gives its own calorific value of 19,800 B.T.U., assuming that no deductions are made. This figure of 32,600 B.T.U., which is evidently too high, then gives the relative heating value of petroleum as compared with coal, as—

$$(8) \qquad \frac{32,600}{14,000} = 2.33 \text{ times.}$$

The limit of perfect utilisation of the air is met with in a proportion of petroleum to coal of about one-third, for which the usual excess of air of 64 cub. ft. per pound of coal provides the 181.1 cub. ft. necessary for the petroleum. The relative value of petroleum to coal calculated as above is then—

$$(9) \qquad \frac{2,560 \times 3 + 19,800}{14,000} = 1.96.$$

These figures represent maximum theoretical values which it is not possible to attain in practice.

With a higher proportion of petroleum these values diminish rapidly. With a consumption of petroleum equal to half that of coal the figure of 1.77 appears to be the limit, and this was approached in some of the experiments made at Indret upon mixed firing.

The values of 3 and above, which have at times been obtained for the relative value of petroleum, as the result of experiments of short duration, cannot, with the proportions of petroleum to which they relate, be justified theoretically by any hypothesis, and must be regarded as inaccurate.

It will be seen in the next paragraph that, with mixed firing, the assumption that all the oxygen is consumed is far from being borne out in practice.

72. *Smoke and its Analysis.*—The only indication as to the completeness of combustion is given by the smoke. Thick smoke indicates incomplete combustion, and is caused by the too sudden cooling of the gases before the hydro-carbons have been burnt. The analysis of the gases is easily carried out by means of the Schloesing and Orsat apparatus, which gives very reliable results, and from which practical deductions can at once be made. The process consists in the consecutive treatment of a certain volume of the flue gases, with the following liquids taken in order:—(1) A solution of caustic potash; (2) a solution of caustic potash and pyrogallic acid; (3) a solution of ammonia and ammonium chloride in the presence of metallic copper. The caustic potash absorbs the carbon dioxide present, the second solution combines with the oxygen, and the third solution effects the removal of carbon monoxide. The residue consists of nitrogen, the water vapour having already been condensed before the gases reach the testing apparatus.

The proportion by volume of free oxygen to carbon dioxide enables the ratio of the total volume of air passing into the furnace to the volume of air utilised for combustion to be obtained. The exact value of this ratio neglecting the carbon monoxide and water formed would be :—

$$\frac{CO_2+O}{CO_2} = 1 + \frac{O}{CO_2} \tag{10}$$

and the equation, giving the proportion of oxygen to nitrogen in the air by volume is :—

$$\frac{CO_2+O}{N} = \frac{20.8}{79.2} \tag{11}$$

The ratio (10), which is the more useful one, varies of course with different samples of gases; it becomes smaller as the intensity of combustion increases, as we have already seen in paragraph 68. When the sample taken contains 8 per cent. of oxygen with a combustion of 20 lbs. per square foot of grate, or 5 per cent. of oxygen with a

combustion of 40 lbs. per square foot of grate, it can be safely said that either the layer of coal is too thin or the draught is too great, so that a thicker layer of coal should be used or the draught should be reduced. When from 1 to 2 per cent. of carbon-monoxide is present, the layer of coal is, on the contrary, too thick, and in order to obtain a good result, the draught should be increased, or a thinner fire employed.

If an excess of unburnt oxygen is combined with an excess of carbon monoxide, then the furnace arrangements are defective, and the boiler cannot yield economical results until some improvement is effected in the rate of combustion.

The following table gives the results of analysis of gases taken from the Belleville boilers of the *Furieux*, tried in 1899, and fitted with economisers :—

Coal burnt per sq. ft. of grate per hour.	Percentage by volume.				$1+\frac{O}{CO_2}$
	CO_2	CO	O	N	
8·19	10·3	0·0	9·2	80·5	1·89
15·38	11·2	0·3	7·8	80·7	1·70
23·6	13·0	0·6	6·0	80·4	1·46
30·72	13·7	0·4	5·2	80·7	1·29

The following analyses were obtained from tests made at Indret on the experimental boiler of the *Jeanne d'Arc* when burning coal only :—

Coal burnt per sq. ft. of grate per hour.	Percentage by volume.				$1+\frac{O}{CO_2}$
	CO_2	CO	O	N	
18·43	11	1	6	82	1·54
28·67	11	1	5	83	1·45
40·96	13	0·5	4	82·5	1·30

In the same boiler, with mixed firing and using a

petroleum burner and steam atomiser, the following results were obtained :—

Per sq. ft. of grate.		Air-pressure in ins. of water.	Percentage of gases.				$1+\frac{O}{CO_2}$
Coal.	Petroleum.	Forced draught.	CO_2	CO	O	N	
		ins.					
15·36	7·58	0·39	10	0	8	82	1·80
	10·24	0·39	10	0	8	82	1·80
20·48	7·58	0·39	10	0	8	82	1·80
	10·24	0·79	8·5	0	9·5	82	2·12
	13·52	0·98	8·5	0	9·5	82	2·12
30·72	7·17	0·98	11	0	7	82	1·64
	11·26	1·18	11	0	7	82	1·64
	15·36	1·58	11	0	7	82	1·64

The entire absence of carbon-monoxide, and the great excess of air are particularly noticeable in the above Table. The following analyses of flue gases from petroleum firing alone, with natural draught, were made by M. Orde :—

	CO_2	CO	O	N	$1+\frac{O}{CO_2}$
1st Trial .	13·2	0	3·6	83·2	1·27
2nd Trial .	12·6	0	4·0	83·4	1·32
Mean . .	12·9	0	3·8	83·3	1·285

The excess of air, which M. Orde considers too high, is, after all, less than that which would have been necessary when burning coal alone. The combustion of petroleum produces a small quantity of water which can hardly be entirely neglected. The analysis of the gases, when made with care, and if their temperature in the funnel is known, gives very accurately the calorific efficiency of the boiler, such as we have defined it above; that is to say, it gives at the same time an indication of the completeness of the combustion and the quantity of heat utilised.

§ 2. TRANSMISSION OF HEAT TO THE WATER AND TO THE STEAM.

73. *Transmission of Heat.—General Principles of Conduction of Heat.*—The transmission of heat from the furnace gases to the water takes place through the metal forming the heating surface in the three following stages :—

(1) From the gases to the heating surface.

(2) Through the thickness of the metal separating the gases from the water.

(3) From the surface of the wall in contact with the water to the water itself.

We have then to examine :—

(1) The temperature of the hot gases, T.

(2) The temperature of the heating surface next the fire, T_1.

(3) The temperature of the heating surface next the steam or water, t_1.

(4) The temperature of the water, or saturated steam, t.

We know the law of transmission of heat through metal.

$$Q = C\frac{\theta}{e} \tag{12}$$

Q being the number of heat-units traversing per second a unit section of one square foot.

C is the coefficient of conductivity of the metal.

θ the difference in temperature $T_1 - t_1$.

e is the thickness of metal in inches.

The following are the values of C for lead, iron, copper, and silver, according to Wiedmann and Franz.*

Lead	0·092
Iron	0·129
Copper.	·746
Silver	1.081

* For iron Newstad gives 0.131 and Angstrom 0.1322.

These coefficients of conductivity are sometimes expressed in terms of the conductivity of silver.

Little is known with regard to the conductivity of the deposits which often cover metallic surfaces, save that, as a general rule, they are extremely bad conductors of heat. The transmission of heat between the hot gases and the walls, and between these and the water, is regulated by unknown laws. It is, however, known that it is not effected by conduction, as fluids conduct very badly, but by convection; that is to say, heat is carried away by the particles of fluid which succeed each other in contact with the metal. Continued movement of the fluid is therefore necessary. It is also known that heat passes more readily between the water and the metal than between the hot gases and the metal—3,500 times more readily, according to Mr Milton of Lloyd's. This figure is, however, only partially justified by the difference between the conductivities of water and gases, which are estimated as being 0.00155 in the former, and 0.000045 in the latter case, silver being taken as unity.

It follows, from the great difference between the conductivities of water and the hot gases, that, whatever their true values may be, t_1 differs very much less from t than T_1 does from T, and as T_1 and t_1 differ very little from each other, the temperature of the containing walls of the boilers under normal conditions approaches very nearly to that of the water. Any cause which tends to prevent the transmission of heat to the water, tends also to increase T_1 and t_1.

As the value of θ in equation (12) is unknown, this equation is of little use until Q is known, when it may be used for calculating the value of θ.

The only difference of temperature that can be measured (and even then only approximately) is—

$$\Theta = T - t.$$

Q can only be determined experimentally as a function of Θ.

Mr Blechynden experimented upon a small boiler having a definite heating surface in contact with the hot gases of known temperature; he measured T, *t*, and the amount of water evaporated, from which he obtained the value of Q.

These experiments, made with different surfaces and thicknesses of metal, gave results which showed that the following law held very generally :—

(13) $$Q = K\,\theta^2,$$

K being a constant for the same surface in contact with the flame whatever the value of θ.

Formula (13) being accepted, it is easy to find the value of K for the whole of the heating surface of a boiler, the evaporative power of which is known.

Let us take the case of a boiler in which each pound of coal burnt produces 14,040 B.T.U., distributed amongst 20.5 lbs. of gas at 3,000° Fahr., which pass out at a temperature of 572° Fahr., abstracting 2,650 B.T.U., and let us assume that the temperature of the water and steam is 392° Fahr. Assuming, finally, that the combustion is 20.5 lbs. per square foot of grate, and the ratio of heating surface to grate surface is 40, we can now proceed to determine Q.

If Q be the total quantity of heat transmitted by one square foot of heating surface, the quantity of heat passing through a small surface, *ds*, is equal to Q *ds*; the decrease in temperature, $d\theta$, of the 20.5 lbs. of gas, taking into account its specific heat, 0.23, will be given by the following equation :—

$$d\theta = \frac{Q\,ds}{20.5 \times 0.23} = \frac{Q\,ds.}{4.715}$$

Replacing Q by K θ^2 (formula (13)) we obtain

$$d\theta = \frac{K\,\theta^2\,ds}{4.715}$$

$$\frac{d\theta}{\theta^2} = \frac{K}{4.715}\,ds.$$

(14) $$-\frac{1}{\theta} = \frac{K}{4.715}S + C,$$

in which S is equal to 1.96 sq. ft. of heating surface, corresponding to a grate surface of 0.049 sq. ft. for 1 lb. of coal burnt per hour.

Assuming the limiting values of Θ, that is, $T - t$, to be 2,642° and 180° we obtain

$$\frac{1}{180} - \frac{1}{2,642} = \frac{K \times 1.96}{4.715},$$

which gives

$$K = 0.0125.$$

The quantity of heat which passes per square foot per hour is then

$$Q = 0.0125\, \Theta^2 \tag{15}$$

in every part of the boiler.

In the furnace, for $\Theta = 2,642°$

$$Q = 79,380 \text{ B.T.U.}$$

At the entrance of the tubes at the tube plate, for $\Theta = 900°$

$$Q = 10,125 \text{ B.T.U.}$$

At the other extremity of the tubes, for $\Theta = 180°$

$$Q = 405 \text{ B.T.U.}$$

From these values of Q, the corresponding values of θ can be calculated by formula (12), care being taken to divide Q by 3,600, as the second is taken as the unit of time.

It is found that, in the furnace, for a thickness of metal equal to $\frac{1}{2}$ in.,

$$\theta = \frac{Qe}{C} = 90° \text{ Fahr.} \tag{16}$$

It will be seen from the law stated in formulæ (2) and (3) that, with a moderate rate of combustion, and a temperature of the outgoing gases not above 572° Fahr., increasing the heating surface beyond forty or fifty times the grate surface has scarcely any effect. This agrees with the results of previous experiments.

As a matter of fact, the gaseous products of combustion in contact with the furnace plates never attain a temperature of 3,000°, but the radiation from the solid mass of incan-

descent coal easily reaches 87,810 B.T.U. per square foot of these plates, that is to say, 30 per cent. of the total heat of combustion, and even more. No experimental data are available for the evaporative power of the furnace plates of an ordinary marine boiler. The examination of the efficiency of the heating surface, which forms part of the furnace, is separately dealt with in paragraph 77, where we find verification of the rapid diminution of Q as shown by the preceding calculations, and also that no advantage is gained by increasing the heating surface S above 40 to 50 times the grate surface G. An interesting experimental verification of formula (15) is given below.

Geoffroy, in 1860-64, measured the evaporative efficiency of the different parts of a locomotive boiler composed of segments placed end to end, the tubular portion in particular being composed of four segments. With a moderate fire, corresponding to a combustion of 20.5 lbs. of coal per square foot of grate per hour, the evaporation was 996 lbs. in the first segment through which the gases passed, and only 128 lbs. in the last one; the ratio between these two figures is equal to 8. But supposing that the difference of temperature, θ, varied regularly from 900° to 180° between the first and last segment, it would have a mean value of 810° in the first segment, and 270° in the last, which gives 9 as the ratio between the two values of θ^2. This agrees fairly closely with the ratio obtained from the evaporation.

More complete experiments than those of Geoffroy have been made since then by the Paris-Lyons-Mediterranean Railway Company. The principal results are given in paragraph 77.

For tubulous boilers it is known that, according to an experiment made by Watt, on the type having free circulation, the row of tubes with which the flame first comes in contact accounts for 60 per cent. of the total evaporation.

74. *Importance of Cleanliness of Heating Surface.*—The cleanliness of the heating surface has a great effect on the value of that surface for transmitting heat, and therefore the numerical value of K (formula (13), p. 192) varies considerably with the cleanliness of that surface. In the experiments made by Mr Blechynden upon a vessel with polished surfaces and containing water, K varied from 0.016 to 0.034, according to the thickness of the shell; the mean value of K in English units was 0.024, which corresponds to 0.021 in French units. An ordinary cylindrical boiler, in good condition, with thick furnace plates and thin tubes, will only transmit

$$\frac{0.0125}{0.024} = 52 \text{ per cent.}$$

of the total quantity of heat which passed through the well-cleaned and even planed, though not polished, surfaces of Mr Blechynden's experimental cylinder. As soon as the plates are fouled, either by deposits of lime or, especially, of grease, the transmission of heat from the boiler plate to the water is considerably reduced. This is indicated by the rise in temperature of the plate.

Although the plates should be clean, their surfaces should be rough and not polished, as they then conduct heat much better, and absorb the heat given out by radiation more readily. In their experiments in the Mechanical Laboratory at Charlottenburg, Wiebe and Schwirrus found that polishing the surface of a metal decreased its ability to transmit heat to water.

They also studied the effect of the nature of the metal and the temperature on the coefficient K; an unexpected result from the Charlottenburg experiments was the discovery that at high temperatures heat was better transmitted by the surface of iron than by that of copper.

The insulating action of the scale, which, was always met with in the old types of boilers fed with sea-water,

has been measured by M. Hirsch at certain parts of the furnaces in a case where the evaporation was very high, and mounted to over 40 lbs. per square foot of grate. The fall of temperature between the water and the wetted surface of the plate was found to be 140° Fahr. with a clean plate, 193° Fahr. when the plate was covered with a layer of scale .04 in. in thickness, and 506° Fahr. when the thickness of the layer was .20 in.

Sir John Durston, the Engineer-in-Chief to the Admiralty, made, in 1893, some researches on the heating of the walls due to the water not being long enough in immediate contact with them. These researches were undertaken with a view of discovering the cause of several boiler failures which had taken place, and the reasons for which were not apparent. The following figures are some of the results of his experiments.

When heating water in an open vessel, made of iron 0.5 in. in thickness, the temperature of the fire varying from 2,190° to 2,500°, the temperature of the bottom of the vessel was 280° when the surface was clean; it rose to 310° when 5 per cent. of mineral oil was mixed with the water. When the bottom of the vessel was covered with a coating of grease, .048 in. thick, the temperature increased to 518°.

When the non-conduction of heat is the result of the formation of bubbles of steam, which are worse conductors even than grease, the result is yet more marked. Sir John Durston measured, by means of fusible alloys, the temperature of the tube-plate of a direct tube or Admiralty boiler, working under forced draught, and burning 92.2 lbs. of coal per square foot of grate per hour, the air pressure being 3 ins. The maximum temperature of the hot gases was 3,090°, and that of the water 356°. The temperature of the tube-plate was found to be 1,060° upon the outer surface, and 716° in the centre of the thickness of metal. It will be seen from these figures that the formation of a steam-pocket may easily lead to the burning of the tube-plate.

When the conduction of heat is prevented by a deposit of soot upon the outer surface of the shell, the results become disastrous as regards the transmission of heat to the water, as the obstacle is on the side of the shell where the resistance to conduction is already excessive. As soon as the deposit of soot becomes at all considerable, the marked falling off in power of the boiler shows that the tubes require cleaning. The coating of soot acts as a preservative to the parts of the boiler in contact with the flame; it causes the loss of units of heat, but reduces the risk of overheating.

75. *Transmission of Heat by Convection.*—The efficiency of a heating surface depends upon the rapidity with which the particles of water in contact with it succeed one another.

As regards convection, tubulous boilers appear to be particularly suitable, especially if the tubes are arranged in a zigzag form; but the difficulty of directing the heated gases through each passage between the tubes frequently counteracts this advantage.

The inferiority of the ordinary plain boiler tubes in cylindrical boilers, can be decreased by the use of Guébhard's spirals or retarders, which are flat strips of metal twisted into a spiral form, and placed inside the tubes so as to cause the gases to take a helical course along the tube. Or else this inferiority can be diminished by the use of Serve tubes, which are fitted with longitudinal and radial webs on the interior of the tube, and so abstract the heat from the centre of the hot gases passing through the tube.

On the water side it is as necessary to get the heated particles of water away from the heating surfaces as it is on the fire side to get the gases that have been cooled by contact with the cold walls away from them. M. Ser has made some experiments on steam in a copper tube

heated by a current of water of variable velocity.* The difference of temperature θ between the fluid on the inside and the outside of the tube was maintained constant. The quantity of heat Q from the equations (13) and (15) were, for the different velocities of water, as follows:—

V in feet	Q in B.T.U.
·32809	516
·9841	939·8
1·6405	1,054·3
2·297	1,172·25
2·953	1,282·75
3·609	1,400·6

Neglecting the first figure, the above results give the following empirical formula for convection:

$$Q = 771 + 168 \text{ V}. \tag{17}$$

As far as the water is concerned, the circulation alone is relied upon to facilitate the transmission of heat by convection, the adoption of the Serve tube in the D'Allest tubulous boiler being merely to increase the amount of heating surface in contact with the water. The disengagement of the steam bubbles, if they are carried away sufficiently rapidly by the circulation of the water, ensures the renewal of the surfaces in contact. The circulation should be the more rapid in a tubulous boiler, as the quantity of steam produced in a given time bears a much greater proportion to the total volume of water contained than it does in the case of a tubular boiler.

The artificial circulation of the water in cylindrical boilers, and in particular the use of an agitator, would appear to facilitate the production of steam.

76. *Heating Surface and Grate Surface.—Ratio between the two Surfaces.*—The quantity of water evaporated per

* "Physique Industrielle," par. L. Ser, 1888, pp. 147 and 225.

unit of time and per unit of area from the interior heating surface of a boiler varies from point to point.

Independently of other causes, this great difference proceeds from the radiation of heat from the burning fuel, which, though not great in the case of a flaming coal, is considerable when the furnace is burning a non-flaming fuel, such as coke, and is also very noticeable when the fire has been left uncharged for some time. Looked at from this point of view, the heating surface may be divided into two parts, direct heating surface and indirect heating surface, the former being the surface which is directly exposed to the grate. An analogous subdivision is used in cylindrical tubular boilers, the fire-box and combustion-chamber being the direct, the tubes the indirect heating surface.

Convection exercises a considerable influence on the flames as well as on the water, the furnace-crowns in particular being subject to very intense heating above the furnace-bridges, on account of the rapidity of movement of the hot gases.

The efficiency of the heating surface diminishes rapidly as the distance from the fire increases; in fact, when a certain limit is reached, the addition of further heating surface has no influence upon the power of the boiler, as was shown by Geoffroy's experiments mentioned above, and as we shall see in detail further on.

For all these reasons the addition of extra heating surface, beyond a certain figure, will not add to the evaporative power of a boiler, and may even reduce it by lowering the velocity of the gases. The evaporative power of the added surface is so small that there is practically no increase in the total calorific efficiency.

It is generally admitted that for boilers intended to be worked by natural draught, the heating surface should be about thirty-five times the grate surface, the tubes comprising four-fifths of this area. This proportion is well suited for

the combustion of 12 to 22 lbs. of coal per square foot of grate; as much as 33 lbs. of coal can be burnt and 8.5 lbs. of water evaporated per pound of coal if the boiler is free from scale.

With forced draught the proportion of heating surface to grate surface should be between 45 and 50 in order to obtain a combustion of from 41 to 51 lbs. of coal per square foot of grate; nothing is gained by exceeding this proportion, even if the draught be increased.

Given the heating surface S and the grate surface G, the rate of combustion with a fairly high efficiency is determined by the empirical formula.

$$C = K\left(\frac{S}{G}\right)^2 \qquad (18)$$

Making

$$K = 0.0225$$

we get

$$C = 27.6 \text{ lbs. per square foot of grate}$$

for $\frac{S}{G} = 35$,

and

$$C = 45.6 \text{ lbs. per square foot of grate}$$

for $\frac{S}{G} = 45$.

If all the values of C given by formula (18) are adopted, the heat turned to account sensibly diminishes, when the rate of combustion reaches or exceeds 40 lbs. per square foot of grate. An attempt to obtain a constant efficiency would need an amount of heating surface unattainable in practice.

The heating surface referred to here, and which should always be employed when stating the ratio of heating surface to grate area, is the surface in contact with the flame. In the case of tubular boilers this is the inside of the tubes, and in the case of tubulous or water-tube boilers it is the outside. It is this surface which offers most resistance to the transmission of heat.

77. *Experimental Determination of the Relation between Heating Surface and Evaporation.*—No accurate experiments

have ever been carried out on the different forms of tubulous boilers used afloat to determine the extent to which the evaporative power varies with the heating surfaces. At Indret, more than forty years ago, the effect of stopping part of the tubes was tried, and the result was much more noticeable on the efficiency of the boiler than on its actual power.

In locomotive boilers, as shown in paragraph 73, M. Geoffroy measured the distribution of the evaporative power over different parts of the heating surface, showing fairly exactly the effect of lengthening and shortening the tubes.

More recently M. Henry, the locomotive superintendent of the Paris-Lyons-Mediterranean Railway, carefully repeated Geoffroy's experiments, with this difference, that he measured the total evaporation with tubes of different lengths, and not the evaporation in different parts of the tubes. He thus determined the effect produced by the removal of part of the tube upon the intensity of combustion as well as upon the evaporative power of the part retained.

M. Henry varied in his experiments the length of the tubes and the draught. His boiler, which was similar to M. Geoffroy's trial boiler mentioned in paragraph 73, consisted of a furnace fitted with removable ferrules; tubes of nine different lengths, ranging from 6 ft. 6 ins. to 23 ft., could thus be used. The boiler was worked at pressures of 1 in., 1.8 ins., and 2.9 ins. of water.

The grate surface, A, was about 26.9 sq. ft., its horizontal projection being 24.1 sq. ft. The heating surface of the furnace was 108.9 sq. ft.; the internal heating surface of the tubes varied from 575.6 to 2,015 sq. ft., which gives values of 25 to 79 for the ratio of heating surface to grate surface.

The other data were :—

Number of tubes	185
External diameter of the tubes . . .	2 ins.
Total area through tubes	3·31 sq. ft.
,, ,, ferrules	2·03 sq. ft.

In order to obtain the highest possible efficiency the thickness of the fire in these experiments was varied with the draught, and the average thickness appears to have been somewhere about 10 ins. When the fires required charging, the fall of temperature in the smoke-box caused a thermometer to make an electrical contact and ring a bell in the stokehold.

The draught, produced by a steam jet, was measured by the difference in pressure between the ashpit and smoke-box. The steam used by the jet was not measured.

The waste gases were analysed by means of Orsat's apparatus.

The results required for purposes of comparison are summed up in the following Table:—

Length of Tubes	ft.	9·84	13·1	16·4	19·7	23·0
Total heating surface . .	sq. ft.	972·2	1,260	1,548	1,835	2,122
Ratio $\frac{\text{Heating surface}}{\text{Grate surface}}$ . .		36·13	46·82	57·52	68·21	78·91
	Ins. of Water.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Combustion per square foot of grate at draughts of	1·0	38·21	36.8	33·1	30·3	28·9
	1·8	53·3	50·4	46·3	43·0	41·3
	2·9	70·8	67·0	61·7	57·2	54·8
Water evaporated per pound of coal at draughts of . .	1·0	7·87	9·01	9·65	9·94	10·20
	1·8	7·87	8·66	9·29	9·58	9·84
	2·9	7·11	8·22	8·85	9·14	9·40
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Total heat efficiency at draughts of	1·0	66·7	79·8	80·0	84·0	83·0
	1·8	63·1	69·7	77·2	80·2	80·0
	2·9	57·9	65·3	...	73·0	75.2
		Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
Temperature of the gases in the smoke-box at draughts of	1·0	739	608	518	460	432
	1·8	813	666	561	500	457
	2·9	896	722	603	534	486
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Loss of heat by the funnel at draughts of	1·0	17·4	13·7	11·4	10·2	9·77
	1·8	19·0	14·7	12·3	11·0	10·3
	2·9	21·2	15·9	13·1	11·7	10·9

The total efficiency of the boiler, as well as the loss in the funnel, is calculated as a percentage of the total heat which would have been produced had combustion been complete,

With perfect combustion 14,190 B.T.U. per pound of fuel would have been developed. Mariemont briquettes, which are similar in composition to Anzin briquettes, were used as fuel.

It will be noticed that the efficiency of combustion estimated from the carbon acid and the ashes and soot, diminished as the draught increased. The diminution was, however small, and independent of the length of the tubes.

The heat turned to account diminished, as shown by the values for the total heat efficiency in the above table, when the draught was increased or the length of the tubes decreased.

The evaporative power of the boiler at all draughts reached a maximum with a length of tubes of about 13 ft. corresponding to a ratio of S to G of 47. At the high rate of forcing of 2.95 ins., the most favourable ratio of S to G was about 57. For a given draught the loss of evaporative power due to either insufficient or excessive length of tubes has not been much more than 10 per cent.

The total heat efficiency reached extraordinarily high values with tubes 19.7 ft. and 23 ft. in length.

The efficiency was remarkably high, as much as 10.2 lbs. of high pressure steam being obtained per pound of coal without correction for temperature; after the addition of a "Tenbrinck" (see page 295) to the furnace, an evaporation of 10.43 lbs. and an efficiency of 85.5 per cent. was obtained. These results are what must be aimed at in the new tubulous boilers for naval use. Although the efficiency scarcely exceeded the usual figures when short tubes were employed, yet it must be admitted that the great increase shown with the longer tubes is not solely due to the extra heating surface. The reduced losses in the funnel must also be taken into account, due to the fact that the air supplied for combustion did not exceed 176 cub. ft. per pound of coal.

In the experiments made at different draughts, the amount of air required per pound of coal decreased, as a

general rule, as the draught increased; the mean consumption of air was 161.8, 152.3, and 142.6 cub. ft. for the three different draughts employed. The thickness of the fire was much greater upon the locomotive than upon the marine boiler.

Following upon these experiments made with an ordinary furnace, M. Henry made three other sets. In this latter series, the baffles were placed above the grate and nearly parallel with it, so as to cause the flames to move towards the boiler front, and take a longer course before reaching the tubes, thus forcing the flames to take a somewhat similar course to that adopted on the *Forban*. The two first baffles were brick arches of different lengths, placed at a height of about 2 ft. 6 ins. above the grate; the third was a "Tenbrinck," placed about 2 ft. above the grate.

These further experiments were made under the same conditions as the first set, different lengths of tube being employed for each experiment. The following results, which are independent of the lengths of the tubes, are the mean of the whole of this latter series of experiments, and show the effect upon the combustion efficiency of thoroughly mixing the gases. The efficiency is based upon the number of thermal units utilised.

		Ordinary Furnace.	Short Brick Arch.	Long Brick Arch.	Tenbrinck
	In. of Water.	Per cent.	Per cent.	Per cent.	Per cent.
Proportion of carbon di-oxide at draughts of	1·0	9·9	7·8	7·0	8·3
	1·8	11·4	7·9	8·1	6·9
	2·9	14·4	8·6	8·5	7·8
Proportion of ashes in ashpit, smoke-box, and funnel at draughts of	1·0	1·45	0·74	0·65	0·88
	1·8	2·66	1·48	1·41	1·50
	2·9	4·77	2·85	2·22	3·13
Combustion efficiency at draughts of	1·0	92·0	95·0	95·0	95·0
	1·8	91·0	94·0	94·0	94·0
	2·9	90·0	93·0	94·0	93·0

These results confirm what modern practice has revealed, the necessity for thoroughly mixing the hot gases, especially with very energetic forced draught, in order to burn the carbon dioxide. It should be noticed that the "Tenbrinck," in spite of the lower temperature of its walls, has not been less effective than the brick arch in ensuring complete combustion. A gain of 3 per cent. in combustion efficiency, however, does not by any means represent the increased efficiency of the return-tube boiler as compared with the direct-tube type.

The results of some evaporative tests which were made after stopping up a portion of the tubes may be noted; the combustion and evaporation decreased in nearly equal proportions, but both of them at a less rate than the decrease in the cross sectional area of the passages for the hot gases.

M. Henry's experiments led to marked improvements being realised in the combustion in locomotive boilers, with the result that the saving effected has much more than paid the cost of the experiments. For marine boilers these experiments are useful for purposes of comparison, as they show what ought to be obtained with properly arranged and proportioned heating surfaces and furnaces capable of ensuring perfect combustion at all draughts. They also form a basis for comparing new types of boilers.

Upon the new tubulous boilers employed in the French Navy experiments have only been made upon the amount of steam evaporated by the different rows of tubes without in any way altering the arrangement of the boiler. The experiments therefore are similar to those of M. Geoffroy and not to those of M. Henry. The most recent results are those which have been published by Mr Watt* and by M. Niclausse.

Mr Watt carried out his experiments upon a small model boiler containing seven horizontal rows of tubes

* "Trans. Inst. N.A." vol. xxxvii., page 264.

arranged like those of the D'Allest boiler. The proportion of steam evaporated by each row of tubes was as follows:—

1st row	60·0 per cent.
2nd ,, . .	24·0 ,,
3rd ,, ...	9·5 ,,
4th ,, . . .	3·5 ,,
5th ,, . . .	1·5 ,,
6th ,, . .	1·0 ,,
7th ,, . . .	0·5 ,,
	100·0 ,,

M. Niclausse carried out his experiments upon a full-sized Niclausse boiler consisting of twelve rows of tubes, the conditions of circulation being those peculiar to this design. The results were as follows:—

1st row	22·30 per cent.
2nd ,, . .	14·80 ,,
3rd ,, . .	10·84 ,,
4th ,, . .	8·57 ,,
5th ,, .	7·43 ,,
6th ,, ...	6·74 ,,
7th ,, .	6·14 ,,
8th ,, . .	5·59 ,,
9th ,, . . .	5·10 ,,
10th ,, . .	4·56 ,,
11th ,, ...	4·15 ,,
12th ,, ...	3·78 ,,
	100·00 ,,

Moreover, M. Niclausse experimented at different rates of forcing, varying the combustion per square foot of grate from 10 to 60 lbs. The results varied very little from the mean of those given in the above tables.

The results obtained by Mr Watt and M. Niclausse, it will be seen, vary considerably, particularly as regards the evaporation from the first row of tubes exposed to direct radiation from the grate. It has been pointed out with reason, that the tubes in the Niclausse boiler being staggered, the direct radiation from the grate would act

upon the first two rows of tubes, which together furnish 37·1 per cent. of the total steam produced.

As the total heating surface for the twelve rows of tubes of the Niclausse boiler was equal to thirty times the grate area, the evaporation obtained from the last rows of tubes is not excessive, especially with a combustion of 40 to 60 lbs. of coal.

It would be very difficult to carry out a similar set of experiments on boilers of the Du Temple type. The only thing that could be done would be to compare between themselves boilers having different ratios of heating surface to grate surface, for example, those of the *Jeanne d'Arc*, with a ratio of 46.5, with those of cruisers of the *Montcalm* type, having a ratio of 41.

78. *Determination of the Amount of Heating Surface.*—From what has been said above it will be clear that although the economy due to an increase of heating surface cannot be always exactly determined, a certain amount of gain is almost sure to be realised, provided that the increase does not materially alter the weight and space occupied. The general method of augmenting the heating surface is to increase the number of tubes and reduce their diameter. Here, as in other problems, conflicting conditions are met with, because on account of the increased resistance to the passage of the gases, and also to the life and safety of the generating tubes, large tubes are to be preferred. In cylindrical boilers the outside diameter of the tubes is generally about 2¾ ins. On the *Sfax* a higher efficiency, without consequent inconvenience in working, was obtained by reducing the diameter of the tubes to 2 ins., and the danger from what is known as "bird-nesting" did not unduly increase. In tubulous boilers with horizontal tubes larger diameters are used—4 to 4½ ins. for Belleville boilers, 3¼ ins. for Niclausse boilers, 3⅛ ins. for Montoupet boilers.

The ratio of heating to grate surface is generally about 30 to 35. With vertical tubes, in boilers with accelerated circulation, the external diameters may be considerably reduced; in the case of torpedo-boats even to 1 in., on the *Jeanne d'Arc* to $1\frac{1}{4}$ ins., on the *Montcalm* to $1\frac{3}{8}$ ins. The ratio of S to G in these boats was respectively 45.8, 46.5, and 41.0.

From the above figures and especially from the Table given in paragraph 77, it will be seen that it is more difficult to predict exactly the number of pounds of water that will be evaporated per square foot of heating surface, than to define the number of pounds of coal which will be burnt per square foot of grate. As the quantity of water evaporated per pound of coal is generally known approximately, as also the draught, the grate surface makes a much better basis of comparison for the powers of boilers than does the heating surface.

Though the heating surface and grate surface are always given with the other particulars of a boiler, the method of calculating them is by no means uniform. The calculation of the grate surface is a comparatively simple matter, and little or no divergence exists. In calculating the heating surface certain portions must be excluded, such, for instance, as the ashpit or lower half of the furnace in cylindrical boilers and the outside of the tube-walls of tubulous boilers. If results are to be strictly comparable it is absolutely necessary that the same method of arriving at them should be used in every drawing office. In tubulous boilers, the external diameter of the tubes is always taken when calculating the heating surface.

79. *Loss by Radiation.—Lagging.* — Boilers are usually covered with a non-conducting substance, in order to diminish the loss of heat by radiation and conduction. This loss has a prejudicial effect in three different ways: it reduces the amount of water evaporated per pound of coal;

it is a source of great inconvenience to the stokers; and it may ignite any combustible material which happens to be in the neighbourhood of the uptake.

In tubular boilers the flues are entirely surrounded by water-spaces; the exterior surface of the boiler, properly so called, cannot therefore exceed a comparatively low temperature, which for usual working pressures is about 400°, and for a pressure of 300 lbs. only 417°. These favourable conditions preclude all possibility of fire, and enable the lagging of the boiler to be easily arranged for.

For a long time, that is to say as long as the working pressures were below 85 lbs. and the temperatures below 320°, boilers were lagged with a coating of felt covered with canvas, having a total thickness of about 1¼ ins. and a weight of 0.8 lb. per square foot. A very careful determination of the non-conducting power of this lagging was made at Toulon in 1889 by M. Brocard, an engineer in the French Navy.

M. Brocard concluded from his experiments that the loss by radiation amounted to 332 B.T.U. per square foot per hour. A boiler with three furnaces like that on the *Jean-Bart* has 656 square feet covered with non-conducting material. This represents a loss of 217,950 B.T.U. per hour, which is equivalent to the combustion of 13 lbs. of coal, or to 1 per cent. of the total heat produced in the furnace with active combustion. This result shows that felt is a sufficiently good non-conductor for all practical purposes, and the loss could be still further reduced by doubling the thickness of lagging, as will be shown later.

Felt, however, has the disadvantage of not being incombustible. It undergoes charring at 309°, a temperature which is often reached in practice, and ignites at 1,200°. Serious accidents have resulted from this, as it takes fire quite as easily from contact with the fire-rakes, ashes and cinders, as from the flame of a lamp or candle. In con-

sequence, the necessity of clothing boilers with some mineral substance, such as asbestos or silicate cotton was early recognised. The experiments of M. Brocard were undertaken to determine the relative non-conducting power of these various substances. The following Table embodies his results :—

Non-conducting material employed.	Weight of lagging per sq. ft. in lbs.	Water condensed in lbs.	
		In 10 hours.	Per sq. ft. per hour.
Felt and canvas, $1\frac{3}{16}$ in. thick . . .	0·9	97·0	0·51
Asbestos, 2 in. thick, with a central layer of silicate cotton $\frac{3}{16}$ in. thick	3·3	88·4	0·46
Pure asbestos, 2 in. thick	3·2	86·4	0·45
Silicate cotton, 2 in. thick	3·6	74·7	0·39
Asbestos, $2\frac{3}{8}$ in. thick, with a central layer of silicate cotton $\frac{3}{16}$ in. thick .	3·6	72·7	0·38
Pure asbestos, $2\frac{3}{8}$ in. thick	3·5	72·3	0·38
Felt and canvas, $2\frac{3}{8}$ in. thick . . .	1·7	48·5	0·25

The above Table shows clearly the superiority of felt, weight for weight, as a non-conductor, and more especially is this the case when price is taken into account.

Mr Charles Norton very ingeniously applied electricity to measuring the non-conducting power of different substances. A reservoir, round which the non-conducting material was placed, was filled with oil and a rheostat immersed therein. A current was passed through, a constant temperature being maintained, and the quantity of watts absorbed by the rheostat gave an exact indication of the value of the various substances as non-conductors.

Upon cylindrical boilers felt was always employed on the sides and for the bottom. The felt lagging upon the bottom of the shell was usually stopped off at some distance from the boiler-front, in order to avoid all risk of contact with the hot ashes, etc., on the stokehold floor. The lower part was usually covered with a thin steel plate about $\frac{1}{16}$ inch thick, so as to prevent contact with the firing tools, which

are frequently placed between the boilers after use. The boiler-front was usually covered with felt where possible, care being taken that the covering was stopped at least 16 ins. from the flues, and the edge secured by a small iron of Z section; further it was not allowed to come within 10 ins. of the floor, nor to be within 6 ins. of any manhole through which candles might be introduced into the boiler.

Where felt was not used, a mineral non-conductor, preferably silicate cotton covered with asbestos cloth, was employed. For the boiler-fronts it would have been simpler to have used mineral non-conducting substances exclusively. When cost is not of primary importance, the use of asbestos cloth to cover the felt has much to recommend it.

Magnesia blocks have been used of late years instead of silicate cotton, and are said to be very much more efficient. The non-conducting properties of silicate cotton depend largely upon whether, when being applied to the boiler, proper steps are taken to prevent it consolidating. One of the most efficient of the mineral non-conductors which has come to the front lately is mica; some interesting tests on this material have been made in Canada by the Grand Trunk Railway. The pressure in the boiler was raised till it reached 150 lbs.; the fires were then withdrawn and the fall of pressure ΔP at the end of one hour noted, and from this the loss of heat Q was calculated. The following Table gives the results obtained :—

	Δ P in lbs. per sq. in.	Q in B.T.U.	Relative value.
Boiler unlagged	54·33	330,900	100
Insulated with silicate cotton	24·03	76,970	33·3
„ „ asbestos cloth and wood cleading	20·05	73,410	31·8
„ „ magnesia blocks	12·94	46,820	20·3
„ „ mica	5·97	21,430	9·2

Other experiments carried out by Professors Capper

and Hudson-Beare have practically confirmed the above figures.

Boilers whose fronts are formed of masonry with an air-casing outside are sufficiently protected on the side where radiation is least desirable, namely, in the stokehold. The cylinders of the main engines are the parts which need the most careful lagging, and where experiments in new non-conducting coverings will best repay research.

80. *Air-casing and Lagging of Smoke-box and Uptake.*—Upon the smoke-box and uptakes, which it is necessary to cover with some non-conducting material, in order to lessen the radiation from the boiler-fronts, two baffles about an inch apart are usually fitted (Fig. 68). Precautions are taken to prevent the heating of the outer baffle due to conduction.

With forced draught and a closed stokehold, these baffles are insufficient, since they do not prevent the heating of the air, which, unable to escape, collects at the top of the stokehold; silicate cotton can in such cases be used with advantage. On the *Fulminant* (which has not a closed stokehold), the use of silicate cotton has enabled the fans to be placed on a platform directly over the boilers. The wood lagging, which was formerly employed upon the smoke-box doors and upon the uptakes, has had to be discontinued on account of the danger of fire.

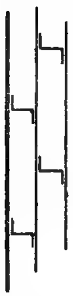


Fig. 68.

At one time a somewhat extensive use was made of plastic non-conducting material. It consisted generally of river-mud mixed with one- or two-thousandths of its weight of horse-hair, and was kept in position by a thin plate; sea mud cannot be used on account of the chlorides contained in it. These plastic coatings are very poor non-conductors; they are, nevertheless, of value for clothing the base of the funnel, the radiation from which into the stokehold is very inconvenient.

The insulation of the funnel itself is always obtained by means of air-spaces. A first casing fixed to the funnel by means of angle-irons forms part of the boiler itself; by carrying it up to the top of the funnel the draught is improved, as the cooling of the air in the funnel is retarded, and the air-space can be also used as a ventilator to the stokehold, and even to the cabins. In order to protect the 'tween decks from the radiation from the funnel, it is as well to surround it with a second casing, forming part of the hull. This second casing, which is always useful, becomes an absolute necessity in the case of many of the tubulous boilers at present in use, the funnels of which are liable to become red hot.

Tubulous boilers, as far as prevention of radiation is concerned, are similar to the smoke-boxes of tubular boilers; their casings have even to submit to still more intense heat than do the smoke-boxes of these latter, since some parts of the casing surround, and even form part of, the walls of the furnaces. The non-conducting material employed usually consists, as regards the lower part, of a covering of brickwork, and the higher portion is covered with a thin layer of ashes between two thin plates. In some instances the upper part of the casing consists of two thin plates with an air space between them, the inner plate having a facing of thin fire-clay tiles or magnesia blocks. A wall of brickwork only 2 ins. thick has the disadvantage of weighing 16.4 lbs. per square foot, not including fastenings; a layer of cinders of the same thickness weighs 7.2 lbs. per square foot, not including the plates. Certain tubulous boilers lose, by this necessity of clothing, an important fraction of their advantage in weight over cylindrical boilers.

The sides of boilers of the Du Temple type are provided with excellent non-conductors in the shape of their side tube-walls which form the exterior of the boiler. Silicate

cotton, and particularly asbestos, have been largely used for lagging the different parts of these boilers, and especially for the fronts.

The double air-casings which are generally on the fronts of these boilers perform two useful functions: firstly, the prevention of radiation with the stokehold; and, secondly, the heating of the air for combustion on its way to the furnace.

CHAPTER VII.

WEAR AND CORROSION.

81. *Wear due to Chemical Action producing Deterioration on the Inside of Boilers.*—The preservation of boilers against destructive chemical action, which operates on them by slow degrees during their whole life, follows rules, common to all kinds of boilers, whether cylindrical or tubulous; this is, therefore, a convenient place to notice them, reserving the study of the resistance of the materials to mechanical fatigue until the different types are separately dealt with.

One very general cause of wear and tear, common to all iron structures that are not painted (as, for instance, the inside of boilers), is oxidation due to contact with air or with water. The action is so well known that it is only necessary to mention here that to be operative the presence of air and of water must be simultaneous; neither dry air alone, nor pure water exhausted of air, has any chemical effect on iron. On the other hand, air, when contained in water, would appear to have a particularly energetic effect when discharged in bubbles against a plate; it would almost seem as if, at the instant when it thus resumes its gaseous form, oxygen had then some of the properties of bodies in a nascent state. Sea-water, however, even when free from air, has a peculiar corrosive action when hot, due to the presence of magnesium chloride. This chloride, when subjected to heat in water, yields magnesia and hydrochloric acid, the reaction taking place under two different circumstances.

In the first case the acid is formed as soon as the sea-water reaches 212° Fahr., and its density is sufficient; and it is this action which explains the rapid corrosion that takes place at leaky joints and rivet-holes.

In the second case the hydrochloric acid is given off, even in the weakest solution, when the temperature is sufficiently high; it is generally admitted that this action commences directly 248° Fahr. is exceeded, that is, at a pressure of 28 lbs. per square inch; it follows, therefore, that in high-pressure boilers, heated to between 250° Fahr. and 400° Fahr., the practice so common in the engine-room of making up losses by using sea-water should be absolutely prohibited.

The rapid destruction of the tubes of the Belleville boiler by local pitting has been explained as being due to the use of sea-water. To overcome this difficulty without discarding such an obviously simple method of making up losses as the employment of sea-water, M. Belleville has advocated the use of lime as a reagent; good results have been obtained, so much so that its use has extended to other boilers, notably to those with steel tubes. The use of the lime has been continued, though that of sea-water has been suppressed.

Unlike chloride of magnesia, other alkaline chlorides, when dissolved in sea-water, do not seem capable of giving off hydrochloric acid unless air be present, but they assist in the deterioration of plates at leaky joints. They may also produce the same effect when heated in the presence of hydrate of silica or of sulphate of magnesia, as will be noted further on when studying the action of solid deposits.

82. *The Action of Fatty Acids.—Chemical Reaction of Saline Deposits.* — The most active cause of the destruction of boiler plates for some years past has been the presence of fatty acids in the feed-water. Surface condensers came

into general use at a time when grease and vegetable oils were the only lubricants employed for the interior lubrication of the engines. The glycerine contained in them becomes separated from the fatty acids immediately on their introduction into the steam cylinder, and these latter are carried on into the boilers, where they attack the plates. The principal seats of this corrosion are the surfaces adjoining the feed-water inlet and those near the water-level, where the acids, floating prior to their saponification, are deposited on the shell. This action is all the more dangerous, as a point of corrosion, once having been set up, is more susceptible to subsequent attacks, and deep pitting may result. Recourse has been had, as a preventative, to the injection into the boiler of a solution of carbonate of soda; but it is found that the carbonate only neutralises the fatty acids after corrosion has already set in; and, further, that the carbonic acid thus formed has a pernicious effect of its own. Carbonate of soda is therefore no longer used, the only alkaline solution still employed being one of lime.

Deposits found at the bottom of boilers often show distinct traces of the salts of copper, distinguishable by their green colour. Some authors have attached great importance to the presence of copper, on the supposition that it set up galvanic action; but it is well known that this action is almost imperceptible when the proportion of copper to iron is so very small. In fact, the existence of galvanic currents has never been clearly manifest even when brass tubes were used; for iron or steel is hardly affected by the vicinity of brass, owing to the presence of zinc in that alloy.

From observations made by M. Normand, when two steels, having different percentages of carbon, are in contact, corrosion occurs in a marked manner on the plate having the lower percentage of carbon.

Deposits formed on inner surfaces act in two distinctly different ways, viz., chemically, as corrosive agents, and physically, as non-conductors, giving rise to overheating. Chemical action is set up both on the surfaces of the shell plates and on the plates forming the flame passages, and probably with the greater energy on the latter. Physical action takes place owing both to mineral and organic deposits, and is confined to surfaces exposed to the direct action of fire.

The chemical action of saline deposits was recently brought to notice by M. Haas, an Engineer in the French Navy, when examining an Oriolle boiler, of which the tubes had become deeply pitted, and even perforated, under the layer of salts which had accumulated in them. This was explained by the reaction between the sodium chloride and the hydrate of silica, giving a silicate of soda and hydrochloric acid, and by a second reaction between the sodium chloride and the silicate of magnesia, giving a silicate of soda and a chloride of magnesia, subject in its turn to decomposition by heat.

$$4\,NaCl + H_4\,SiO_4 = Na_4\,SiO_4 + 4\,HCl$$
$$4\,NaCl + Mg_2\,SiO_4 = Na_4\,SiO_4 + 2\,MgCl_2$$

The corrosive effect of saline deposits does not seem to be noticeable at temperatures between 212° and 248° Fahr., at which boilers, fed with sea-water, used formerly to be worked; for these boilers often returned to port with the water-spaces coated with deposits and yet with their plates intact. Indeed the engineers used carefully to produce a thin deposit on all the plates, furnaces, combustion-chambers, etc., to prevent violent ebullition and for the better preservation of the boiler.

The physical action resulting from deposits has always been manifested by the production of blisters in furnace plates and by damage of a similar kind; this action is

particularly to be feared on the tube-plates, to which the water has difficulty in obtaining access owing to the large production of bubbles of steam on their inner surfaces.

Mineral oils, deposited on a plate, form a brown varnish which is a particularly poor conductor of heat, as has been pointed out in paragraph 49, and which, although very thin, may give rise to overheating of the plate. These dangerous deposits are formed when a boiler is emptied without having the greasy substances floating on the surface of the water previously removed by means of the surface blow-off or scum cock; all the surfaces, whether vertical or horizontal, become coated with oil as the level of the water drops. Deposits of this nature explain to a certain extent those collapses of fire-boxes which happen sometimes on the portions most exposed to the fire.

As will be seen from the foregoing, corrosion always occurs on the surface of the plate in contact with the water.

83. *Principal Precautions to be taken to avoid Corrosion.*— The precautions to be taken for the preservation of boiler shells have been dealt with in the preceding paragraph. They may be summed up thus:—

When designing the shells they should have from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. added to their thickness to allow for corrosion.

Plates exposed to the direct action of fire should be single; red-lead joints should on no account be allowed.

The greatest care must be taken that all seams are perfectly tight, and particularly the tube-plate joints, and the use of solid drawn tubes should be insisted on, as it is always in the weld that pitting occurs, not to speak of the danger of their splitting in tubulous boilers.

No moist air should be allowed to remain in a boiler when it is not in use. The best way of keeping such air out is to heat the air in the boiler by introducing charcoal

warmers through the manholes, and then hermetically closing all openings; or the boiler may be filled up with distilled water that has been deprived of air, with a little lime in it; this last method is frequently employed, especially with tubulous boilers at the present time.

While the boilers are at work, numerous precautions have to be taken, which are partly dependent on the management of the engines. The use of tallow, or vegetable oils, for the lubrication of the cylinders should be strictly prohibited, none but mineral oils should be allowed, and even of these only the absolutely necessary minimum should be permitted. The design of slide-valves and of piston-packing has been an object of special study of late years with the view of suppressing, if possible, all interior lubrication. Even the stuffing-boxes of the main piston-rods and valve-rods are now lubricated with mineral oil.

The condenser tube-joints should be carefully watched, and any loss should be made good with distilled water, to the complete exclusion of sea-water. Sea-cocks on condensers should be condemned, even where they have already been fitted. In its transit from the condenser to the boilers, care should be taken to prevent the feed-water becoming mixed with air. On the other hand, as it is essential that the feed-water should be filtered and cleared of grease, the efficiency of filters and separators should be carefully maintained.

The injection-heaters described in paragraph 196 are used to rid the feed-water of its air. The surface heaters perform the same service, but to the detriment of their own tubes. It is always prudent to prevent the feed-water entering a nest of tubes before it has become thoroughly mixed with a body of water that has been freed from air by ebullition. The same result may also be attained by spraying the feed-water into the steam space.

In spite of all precautions, a certain amount of mineral

oil is bound to reach the boilers; it is therefore desirable to use the surface blow-off frequently while under steam. Should greasy deposits have occurred, it will be necessary thoroughly to wash the boiler out with soda. The solution of caustic soda used for this purpose in the Messageries Maritimes is fixed at about 5 per cent.; the liquid is brought to boiling point and kept simmering for about an hour, after which the boiler is thoroughly emptied and cleaned out.

The use of zinc as a preservative has become very general, as has also that of lime in the feed-water; but this latter should be applied with discretion, for it has happened, on some ships, that lime carried over by the steam into the cylinders has caused abnormal wear and tear of the rubbing surfaces.

Finally, when the whole of the boilers are not in use, it is important to watch and see that all valves, whereby steam might find its way into the empty boilers, are tight.

In the matter of boilers, and indeed of engines in general, it is well always to bear in mind that even the smallest precaution has its importance, and that none are insignificant enough to be neglected with impunity.

84. *Employment of Nickel Steel.*—The progress which has been made in the metallurgy of nickel, and the valuable properties which this metal imparts to steel, enabling it to resist corrosion, increasing its tensile strength and its elastic limit, have brought nickel steel into use for the construction of boilers, and especially for the manufacture of tubes. On the subject of corrosion, which is the one we are here dealing with, the reader is referred to the paper by Mr Howe, read before the International Testing Association in 1900. From experiments made at Sandy Hook on 26 per cent. nickel steel immersed in sea-water for two years, Mr Howe found that the corrosion was only

one-third of that of ordinary steel or soft iron. From a number of other experiments made, both hot and cold, with alkaline and acid solutions, the 20 per cent. nickel steel showed practically the same superiority. In plates of ordinary nickel steel containing only 3 per cent. of nickel, the corrosion in the sea amounted to 75 per cent. of that of soft iron and ordinary steel.

In some tests with 3 per cent. nickel steel, there was no difference at all, and Mr Carnegie even found that in fresh water the 3 per cent. nickel steel corroded faster than ordinary steel.

Putting aside the question of its resistance to rupture, and its ductility, the nickel steel which is most suitable for boilers, is that containing from 20 to 26 per cent. of nickel.

A series of experiments were made in 1899 by Mr Yarrow to obtain as much information as possible under the normal conditions of working to which the boiler tubes are exposed. The comparison made between ordinary soft steel, and steel containing from 20 to 25 per cent. of nickel, yielded the following results:

When cold, with water containing half its weight of hydrochloric acid, the corrosion represented by the total loss of weight, is for nickel steel, only one-sixteenth of that for ordinary steel.

After being repeatedly brought up to a red heat, alternated with cooling in water or air, the ratio of loss of weight was 1 to 2.8 and very closely approached the one-third cited in Mr Howe's experiments.

When heated externally for six hours, with a continuous current of superheated steam passing through the tubes, the ratio of loss of weight fell almost to one-eighth; but the ratio of time until local perforation occurred was 1 to 2.4.

One may therefore say roughly that the life of a boiler can be trebled by the adoption of 25 per cent. nickel steel,

Although this result is a long way short of that obtained with the brass tubes used in the old days, it is of great importance, and cannot be put aside merely on account of first cost, even though the tubes do cost about five or six times as much as ordinary steel tubes. It now lies with the metallurgist to reduce the cost.

PART II.

TUBULAR BOILERS.

CHAPTER VIII.

CYLINDRICAL BOILERS.

§ 1. PRINCIPAL FEATURES.

85. *Single-ended Marine Boilers.*—The different forms of boilers enumerated in paragraph 13 will now be considered in detail and further examples given.

The so-called "marine" boilers are cylindrical return-tube boilers. They are sometimes called "Scotch" boilers, owing to their having been used, as far back as 1862, by the firm of Randolph Elder on the *Velasquez* and the *Murillo.* They took the place of the old rectangular boilers, similar in principle, which prior to that date had been known as "marine" boilers. These rectangular boilers were not equal to a pressure of more than 17 lbs. per square inch. Cylindrical boilers began with pressures of about 55 lbs., and pressures in these have now risen to 200 lbs. and over, and in tubulous boilers to 300 lbs. and over.

Amongst boilers known as cylindrical boilers, a considerable number were greater in height than in breadth, being, as a matter of fact, composed of two half cylinders separated by flat pieces, and were generally known as "elliptical" boilers. Another form was used for a long

time in the American Navy, in which the back and front, instead of being flat, were cylindrical in the upper portion forming the steam-chest; neither of these forms are at present in use.

When boilers are placed athwartships, with the stokehold running fore and aft, the lower portions of the back of the boilers are often cut away to fit the shape of the hull, thus giving a more roomy stokehold.

The following portions of the boiler are always surrounded by water.

1. The furnaces.

2. The combustion-chamber.

3. The nests of tubes, corresponding to the furnaces, which return the hot gases to the front of the boiler.

The hot gases, on emerging from the tubes, reach the chimney by smoke-boxes exterior to, and independent of, the boiler.

There may be one, two, three, or four furnaces, and when there are more than two they are placed at different heights. They are cylindrical in form and vary in diameter from 2 ft. 6 ins. to 3 ft. 6 ins. By increasing the number and reducing the diameter of the furnaces the grate area can be increased and a greater quantity of coal consumed; on the other hand, by increasing the diameter of the furnaces and reducing their number, more perfect combustion is obtainable, and the production of steam is proportionally greater. Flaming coals require big furnaces. Generally speaking, large diameters would be preferable had not the strength of the furnaces to be taken into consideration, as the liability to collapse increases more rapidly than the diameter. The combustion-chamber, which receives the gases from the furnace and distributes them amongst the tubes, is the seat of a very active combustion and forms an indispensable prolongation of the furnace. This prolongation is all the more effective, as the reversal

DRÔME.

CYLINDRICAL BOILER.

Scale 25 mm. = 1 mètre.

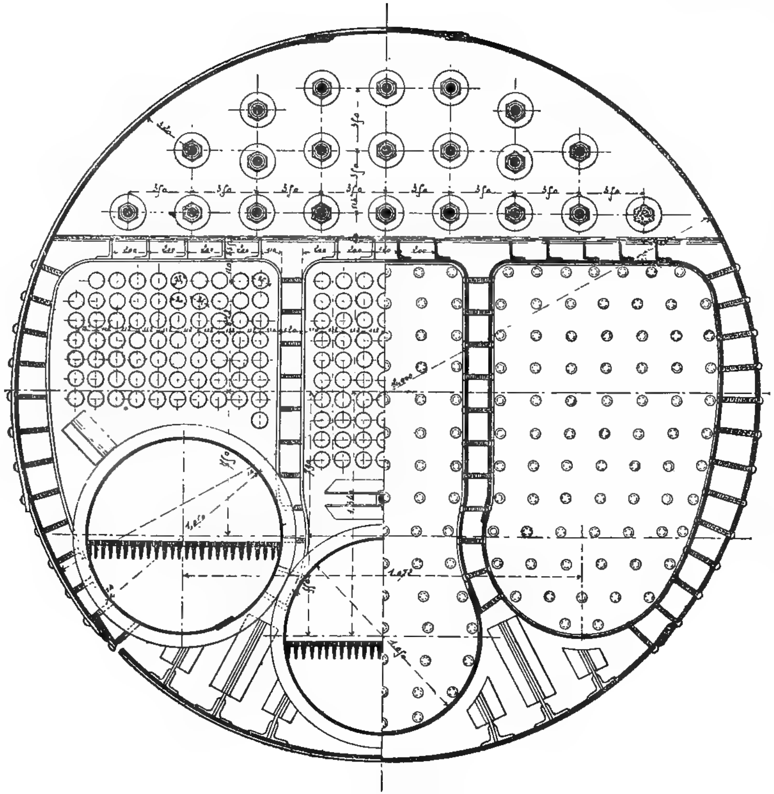


Fig. 69.

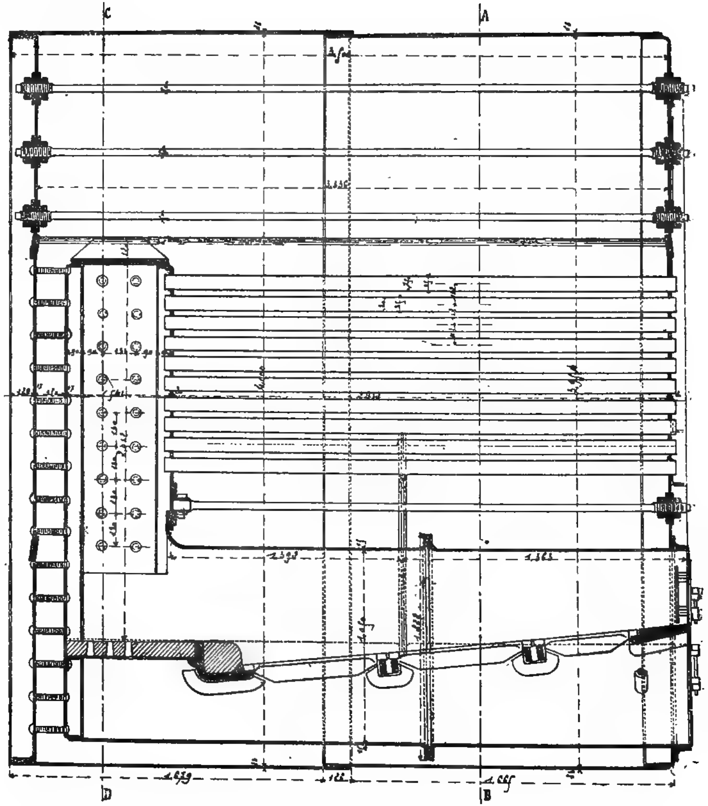


Fig. 69A.

of the flame, which takes place in it, agitates the gases and brings the combustible particles into intimate contact with the particles of air. This chamber is generally made equal to half the diameter of the furnace plus 12 ins. It would, perhaps, be an advantage to make it even bigger. Combustion is never perfect; the volume of smoke issuing from the funnel, especially while stoking, is a proof of this. Indeed, in practice, the results fall a good deal short of the ideal furnace which would send into the tubes the products of perfect combustion and nothing else, and the re-ignition of the gases at the foot of the funnel, which now sometimes occurs, would not then take place.

In some cases there is a single combustion-chamber common to all the furnaces, and from which all the tubes start (Fig. 72); in others there are water-spaces dividing the combustion-chamber into as many compartments as there are furnaces (Figs. 69 and 70).

These water-spaces add to the heating surface, and, in addition, apportion the flames more equally by confining to each nest of tubes the gases proceeding from the furnace immediately beneath it, and hence the arrangement shown in Fig. 71 is not to be recommended.

In the mercantile marine this subdivision by water-spaces is not often adopted. On men-of-war, on the contrary, the combustion-chamber is generally subdivided. This difference is due to the exigencies of forced draught on men-of-war; with forced draught and a single combustion-chamber, some of the tubes are very liable to excessive heating.

86. *Double-ended Boilers.* — Boilers fired from both ends were first introduced into the mercantile marine, and it is on merchant ships that they are used to the best advantage, that is, with a single combustion-chamber common to

"LORRAINE" AND "SAVOIE"

OF CIE. GÉNÉRALE TRANSATLANTIQUE CYLINDRICAL BOILER WITH FOUR FURNACES.

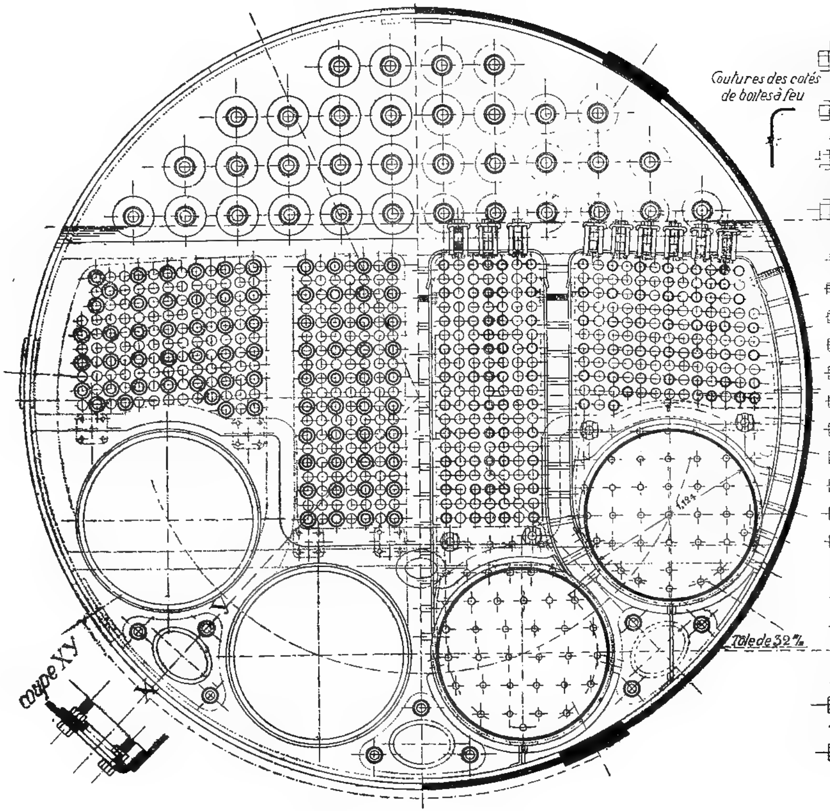


Fig. 70.

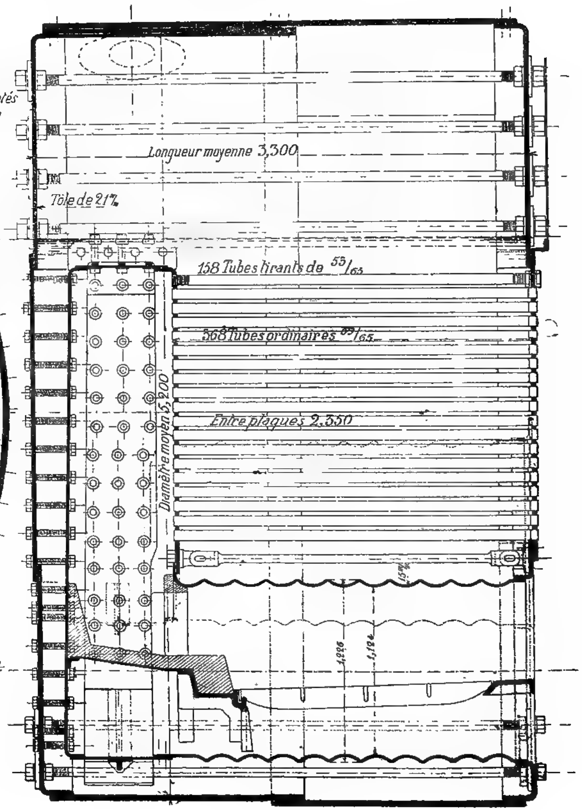


Fig. 70A.

WHITE STAR LINER "GERMANIC."

SINGLE- AND DOUBLE-ENDED BOILERS.

Scale $\frac{3}{16}$ in. = 1 foot.

Design No. 1.—Combustion-chamber common to two furnaces at the same end of the boiler.

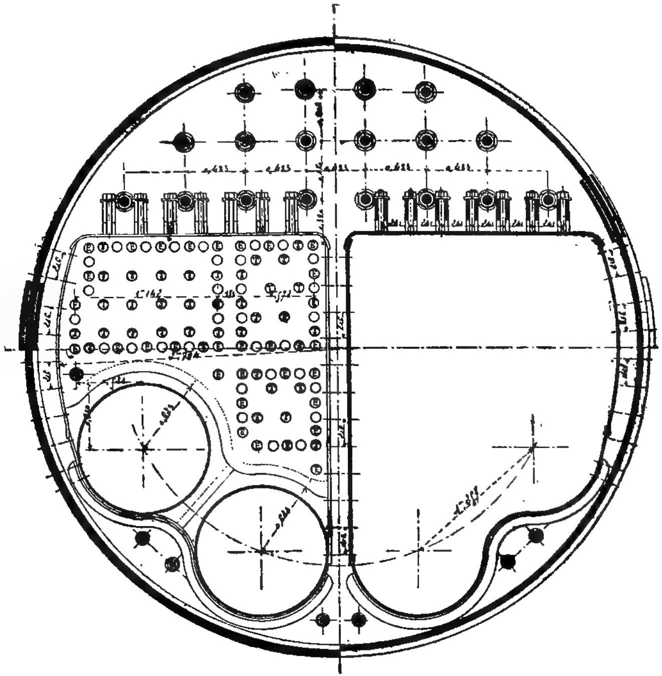


Fig. 71.

Combustion-Chamber.

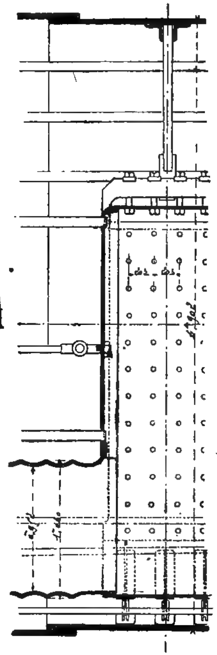


Fig. 71B.

Design No. 2.—Combustion-chamber common to two furnaces at opposite ends of the boiler.

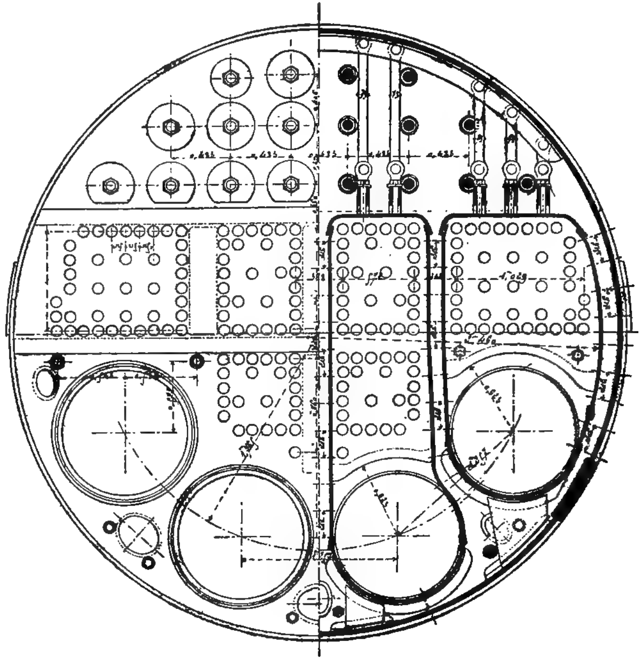


Fig. 71A.

both ends and with a longitudinal vertical division down the centre (Figs. 71, 71A, and 71B.)

The design is thus very much simplified as it suppresses the water space at the end of the single-ended boiler, where there is apt to be difficulty with the stays.

In double-ended boilers the depth of the combustion-chamber is usually made 1 ft. in excess of the diameter of the furnace. This realises a saving over two single-ended boilers placed back to back, of 1 ft., plus the thickness of two water spaces, plus the space usually left between the boilers, equal to, say, about 3 ft. 3 ins. The saving in weight is also considerable.

Double-ended boilers with a single combustion-chamber were especially prone to leaky tubes when under forced draught, and consequently separate combustion-chambers were provided for each end of the boiler (Figs. 72 and 72A).

If the stoking and forced draught were always equally distributed there would not be the same objection to the combustion-chamber common to both ends of the boiler, but nevertheless, the two types seem to be used indifferently. It will be seen, however, that double-ended boilers on war-ships lose a great proportion of the advantages, as to space occupied, weight, and simplicity of construction, that they possess on merchant ships.

On certain liners, the *Lucania*, the *Campania*, and the *Germanic*, for instance, there is a common combustion-chamber for the two corresponding furnaces at each end (Fig. 71B).

87. *Direct Tube or Admiralty Boiler.*—Instead of placing the tubes above the furnaces, so as to reverse the gases, they may be arranged as a prolongation of the furnace, and at about the same height, but separated from it by the combustion-chamber (Fig. 73). This arrangement considerably reduces the diameter of the boilers and enables

COLUMBIA.

DOUBLE-ENDED CYLINDRICAL BOILER.

Scale 24 mm. =1 mètre.

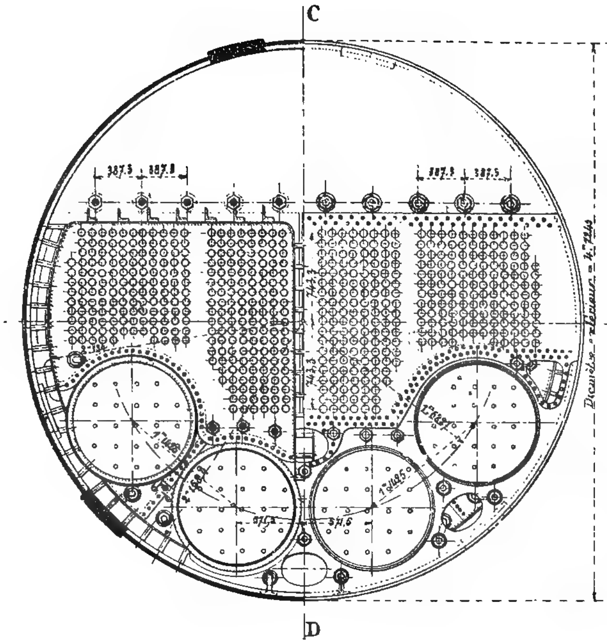


Fig. 72.

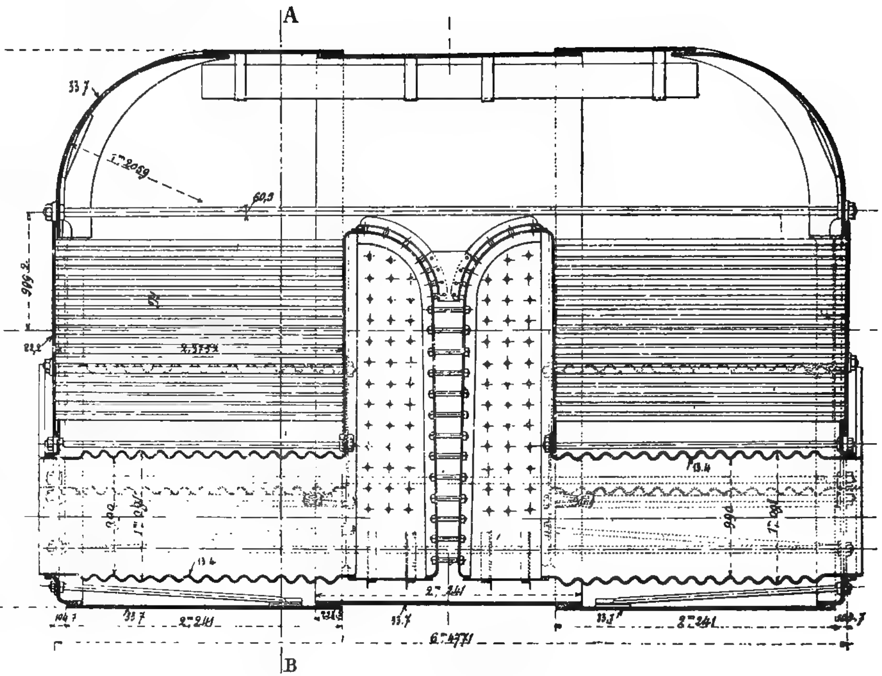


Fig. 72A.

LINOIS.

ADMIRALTY OR DIRECT-TUBE TYPE BOILERS.

Scale $\frac{1}{30}$ of full size.

Half elevation and half section on C D.

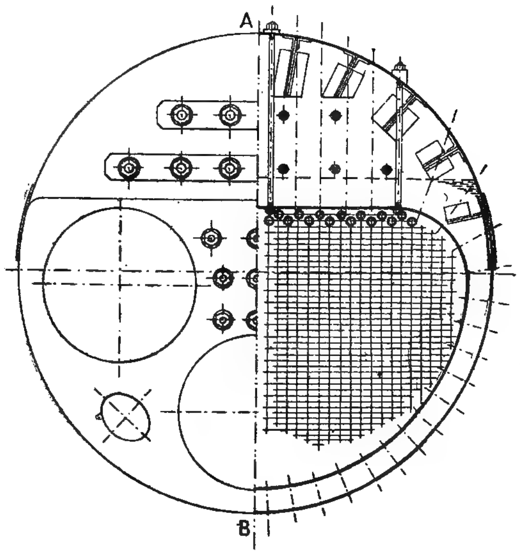


Fig. 73.

Horizontal section on A B.

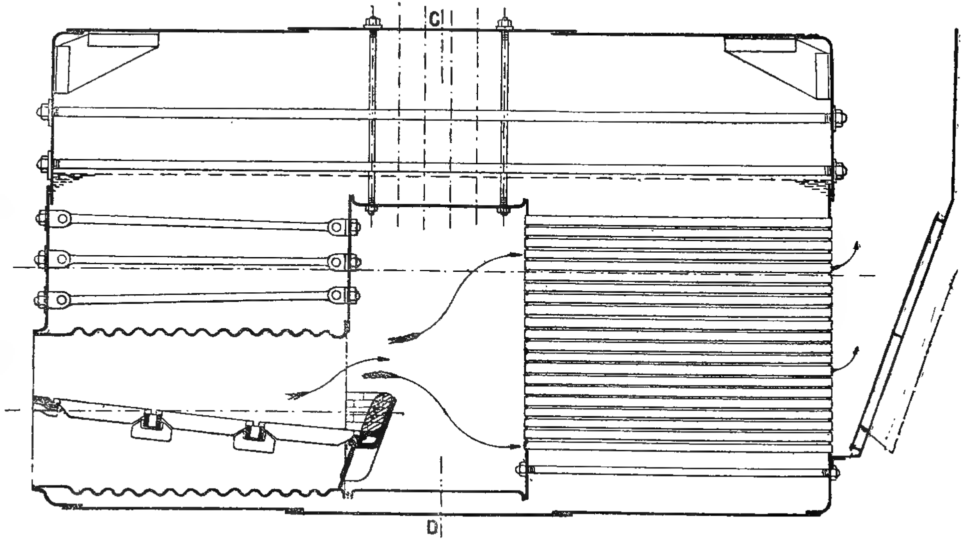


Fig. 73A.

them to be placed under the armoured deck, where there would not be sufficient head-room for return-tube boilers. Owing to the smaller diameter of the boiler, the strength of the shell is proportionally augmented; the working pressure can, therefore, be increased without thickening the shell-plates. Finally, in the Admiralty, or direct-tube type of boiler, the length of the tubes is not limited by the length of the furnace as is the case in the return-tube type.

The disadvantages attending the use of direct-tube boilers are that the hot gases are not so well mixed, and that the tubes are more unevenly heated. The furnace crowns, being very near the water-level, and being exposed to intense heat, are much more liable to over-heating should a fall in the water-level occur. This danger is also greater at the top of the combustion-chamber, which, though not necessarily nearer to the water-level, is much nearer to the furnaces, and therefore to the hottest gases. Further, on account of the length of the boiler, for an equal angle of inclination, the effect on the water-level is much greater. Finally, the unequal expansion of the various parts of the boiler is more pronounced, especially at the top and bottom, due to the increased ratio between the length and the diameter of the boiler; the local strains are also more severe on account of the comparatively feeble circulation in long and low boilers. For all these reasons, and for others of less importance, direct-tube boilers were only used in cases of absolute necessity, and have now been abandoned owing to the adoption of tubulous boilers.

In direct-tube boilers the combustion-chamber is necessarily longer than in return-tube boilers, and, when using forced draught, for reasons already stated, but which hold with even greater force, the combustion-chamber of direct-tube boilers should be fitted with water-spaces.

Some very unsuccessful attempts have been made to

BOILER OF THE *FLEURUS*.

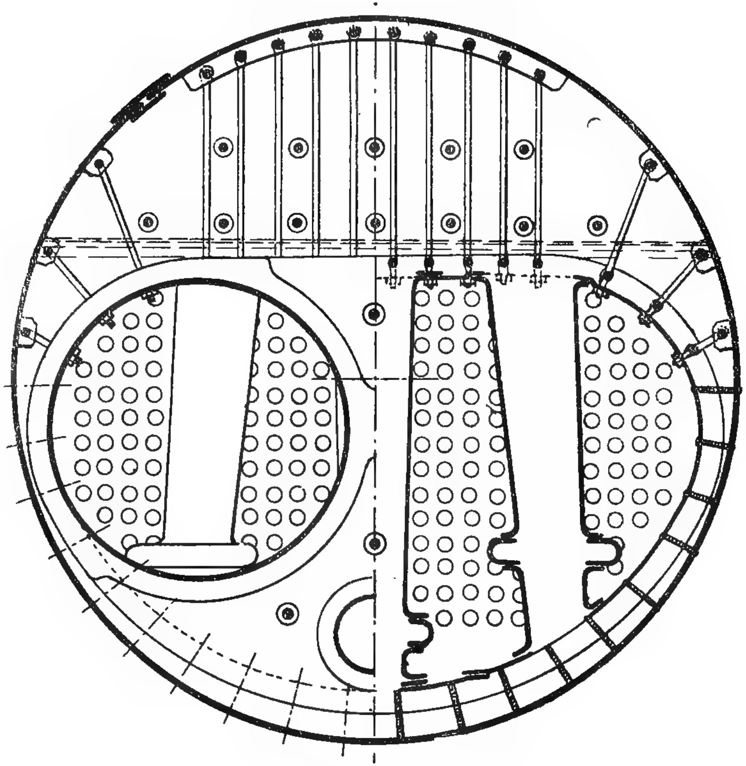


Fig. 74.

BOILER OF THE *SURPRISE*.

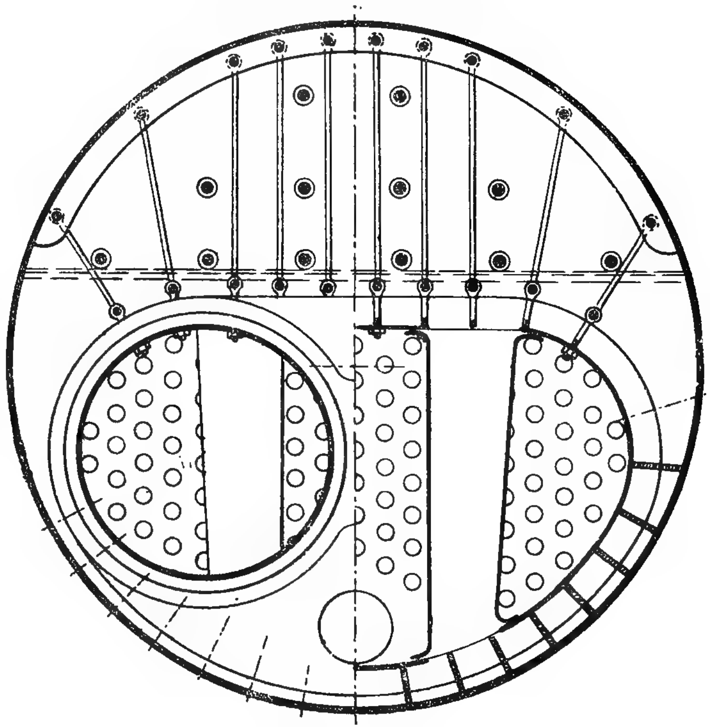


Fig. 75.

increase the heating surface of the combustion-chamber by interposing water-spaces as a screen to the more exposed tubes,* or by fitting large cross tubes. Fig. 74 gives the first installation of this kind on the *Fleurus*, and Fig. 75 that actually in use on the *Surprise*. Baffles or screens composed of fire-brick have also been fitted to several boats to direct the course of the gases, and have the advantage of thoroughly mixing the gases before they reach the tube-plate.

Direct-tube boilers must always be single-ended; there is a simple reason for this, quite outside the question of length, and that is that it would be impossible to sweep the tubes while under weigh.

The "direct-tube" boiler is generally known as the "Admiralty" boiler, on account of its former extensive use in the Royal Navy; in France the use of this form of boiler was for some time limited to gunboats.

When the term "marine" or "marine type" boiler is used in this treatise, it is always with reference to the return-tube boiler.

§ 2. CONSTRUCTION.

88. *Furnaces.*—Each furnace is divided into two parts by the grate; the furnace above, the ashpan below. The furnace itself is of necessity horizontal, but the fire-grate generally has a slope of 1 in 10 towards the back.

This slope, which is indispensable for firing purposes, divides the furnace in a rational and correct manner, as it gives an increasing area for the gases of combustion and a gradually decreasing one for the supply of air. The slope

* This, at any rate, is what was attempted in the locomotive boilers with rectangular fire-boxes, suggested, no doubt, by the "Tenbrinck" arrangement. (See Fig. 131A.).

of the grate might, perhaps, be increased; but it is limited on the one hand by the necessity for leaving sufficient room under the grate for drawing the ashes, and, on the other hand, by the serious diminution of grate area which would result from any considerable departure from the horizontal. It might possibly be of advantage to give the whole boiler a slight backward slope; but this has not yet been tried.

The length of the fire-grate is arbitrary; it is, as a rule, better to make it shorter than the furnace; if possible, it should not exceed 6 ft. in length, although grates 7 ft. in length are common in the Royal Navy. When forced draught is used, and the grate surface has not been definitely determined, it is preferable to keep the length down to 5 ft., and proportionally to increase the draught. The length of the fire-grate is of great importance, more especially when the stokers are not very experienced men. With long fire-grates, the coal is liable to be unevenly distributed over them, the consequent ill effects of which have already been pointed out. On torpedo-boats with highly trained stokers and tubulous boilers, grates have been made as long as 7 ft. 3 ins., but this length has not been reached in the case of cylindrical boilers.

The fire-doors are pierced with holes and fitted inside with baffles to prevent overheating; they must be capable of being opened and shut very quickly so as to admit as little cold air as possible. Those with horizontal hinges and counter-weights are better in this respect than the ordinary types with vertical hinges and double doors. This point will be further dealt with in Chapter XVI.

There are many different types of ashpit-doors, between which there is very little to choose. Note should be taken of the bar placed at the entrance of the ashpit for working the firing tools, which is sometimes made adjustable.

89. *Furnaces Composed of Separate Rings.—Corrugated*

Furnaces.—In modern boilers the furnaces are always cylindrical in shape, to resist the external pressure of the steam. The question of the stresses to which their sides are exposed is an intricate one. The cylindrical shape, while keeping the structure in stable equilibrium as regards internal pressures, leaves it in unstable equilibrium as regards external pressures.

Any deformation, which causes the interior diameters to vary at any one point, produces a bending moment, which the plates are incapable of resisting, with the result that

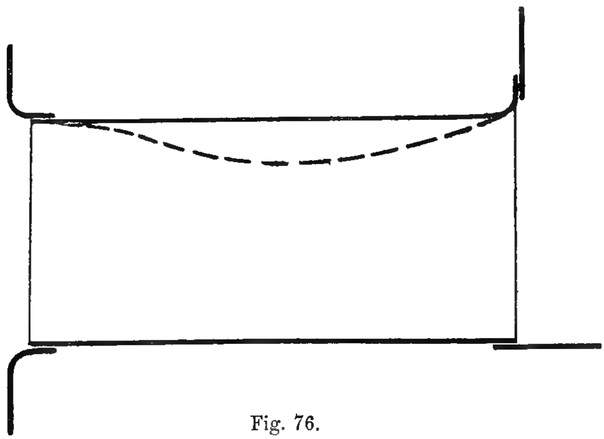


Fig. 76.

the deformation continues to increase until the furnace breaks down. Besides, especially in the furnace, there exists an initial cause of deformation, produced by the firing itself, since the upper part, or crown, is highly heated by the fire, while the lower part is vigorously cooled by the current of air in the ashpit.

The resistance of furnaces to collapsing depends not so much on the thickness of the plates as on the means taken to strengthen them. Deformation cannot take place at the extremities of the furnaces on account of their being riveted to the front and back tube-plates. The effect

of these two end-plates is felt over the whole length of the furnace, as any collapsing draws the back and front tube-plates closer together, which the internal pressure of the boiler tends to resist. The correctness of this view may be questioned. Any straining of the attachment of the furnace to the end-plates must have a pernicious effect. It has been urged in favour of corrugated furnaces that they can expand and

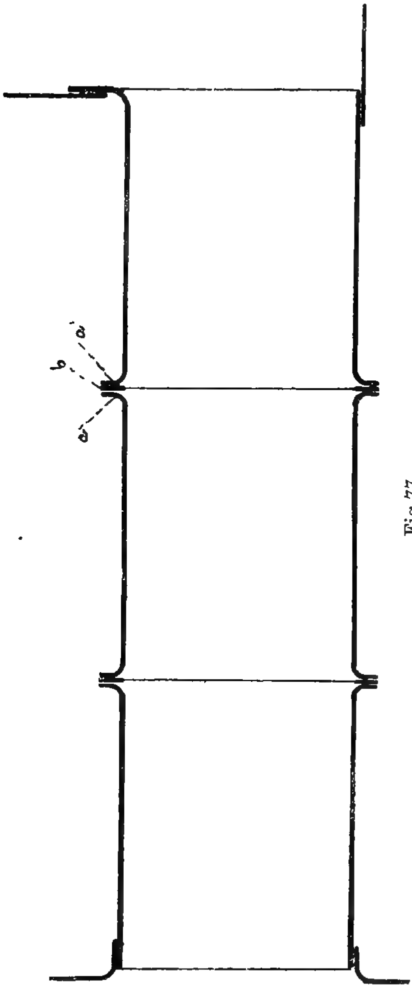


Fig. 77.

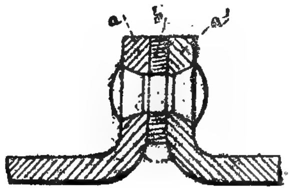


Fig. 78.

contract without unduly straining the joints; it is clear that the end-plates cannot be entirely relied upon as a means of preventing collapsing.

External rings of plates and angle-irons are not used to strengthen the furnaces, for the reason that by doubling the thickness of metal there is a liability to overheating wherever the plates are not in direct contact with the water. On the other hand, furnaces may well be built up of a series of rings, with their

edges turned up and a ring riveted between them and forming ribs, as shown in Fig. 77. The turned-up edges are shown at *a* and a^1, and the ring or washer at *b*; this is always used, not so much to add to the strength of the joint as to protect the rivet from the fire by the inner portion of the ring.

Many furnaces are built up in this manner; in well-equipped workshops a special tool is employed for turning over the edges. The rings which make up the furnaces are necessarily without longitudinal seams; the plates are feather-edged and welded together.

The operation of welding is detrimental to the plates (especially when of steel) more particularly where the part that has been raised to a welding heat joins the colder portion of the plate; thus furnaces of welded plate are liable to give way, not at the weld, but close to it.

In riveted furnaces, it may be noted that the upper part is placed inside and the lower part outside, as in Fig. 79, to avoid a little inside ledge on which coal would lodge.

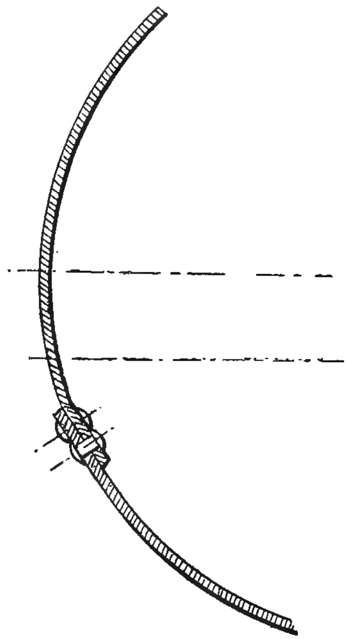


Fig. 79.

As a matter of fact, furnaces are now usually made of corrugated plates, the shape of which offers a certain resistance to bending. The oldest and most extensively used are Fox's furnaces (Fig. 80), which are wavy in section, with corrugations about half the depth that would be given to flanges. They are carefully made, and the weld, which is very good, is not liable to the weakness mentioned

above. For a long time past the Fox furnaces have given every satisfaction; but since pressures have risen to 150, 170, and even 200 lbs. per square inch, while the depth of corrugations remains unchanged, they do not come up to present requirements, and many cases of collapse have occurred. A noticeable feature of the Fox furnace is that, owing to its corrugations, and therefore greater elasticity, more pronounced permanent deformation may occur, without serious consequences, than is the case in the ordinary furnace. The furnace crowns may even drop on to the bars themselves without causing any excessive local strains, or unduly straining the end-plates. This happened on the trial-trips of the

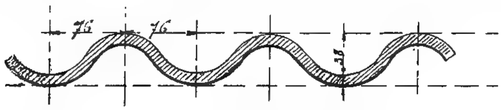
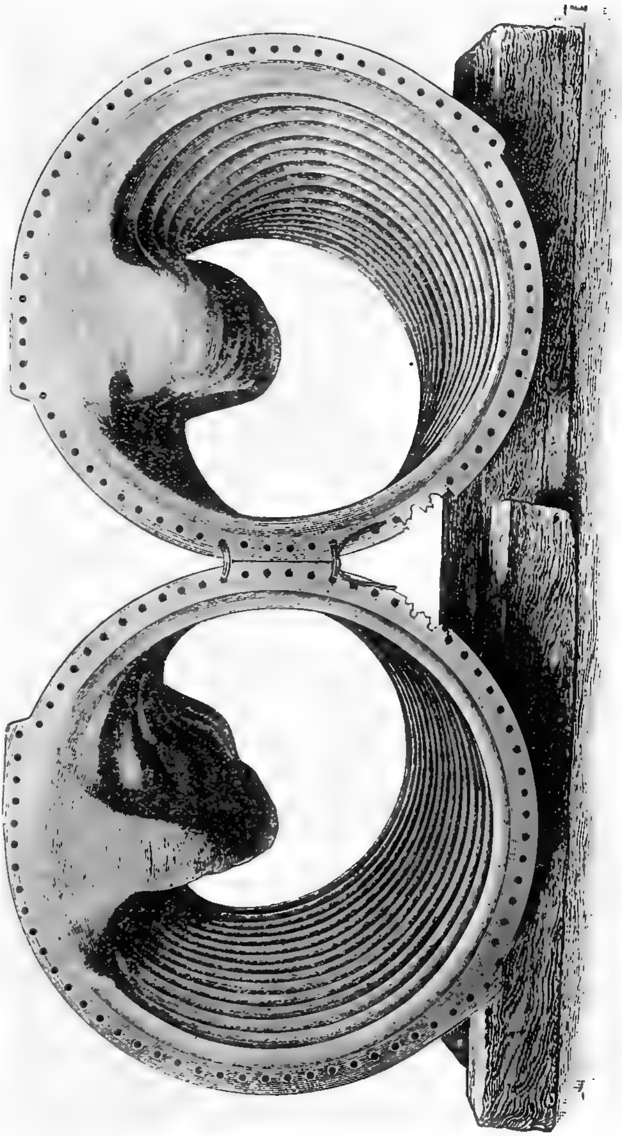


Fig. 80.

Dupuy-de-Lôme and the *Wattignies*. Fig. 81, taken from a photograph, shows a pair of the furnaces of the latter ship as they appeared after the trials. As the boilers in question are of the direct-tube type and the crown of the furnaces is very near the water-level, the accident might have been attributed to some overheating owing to shortness of water; but collapses, similar in every respect, have happened on liners with boilers of the return-tube type; any overheating in this case could only have been due to some calcareous or mineral-oil deposits on the crown of the furnace. These excessive deformations have been singularly free from serious results; there was no tearing or ripping of seams or plates, thereby proving the high quality of the materials used.

To guard against these deformations, there is no other way than to watch carefully for any small changes of shape which precede them, and to restore the correct diameter with a screw-jack as soon as any ovalisation is apparent.



FURNACES OF *WATTINGNIES* AFTER COLLAPSE.

Fig. 81.

The subsequent use of the boilers, after undergoing these extensive repairs, testifies to the confidence placed in the Fox furnaces, but there is no guarantee against the recurrence of similar accidents, and the adjoining parts are liable to become strained.

The constant exposure to accidents similar to those which occurred on the *Dupuy-de-Lôme* and the *Wattignies*, has led to the introduction of a modified form of Fox

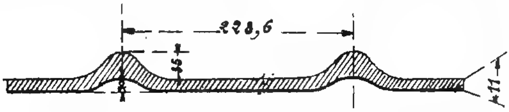


Fig. 82.

furnace, which, while diminishing the area of the plates, and consequent liability to deformation, maintains a reasonable amount of longitudinal stiffness. With this aim in view, several new designs have been brought out,

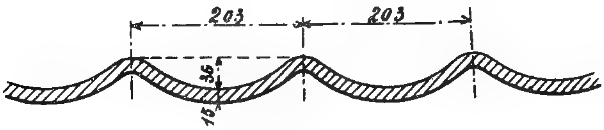


Fig. 83.

but those in most general use are the Purves furnaces (Fig. 82), and the Morrison (Fig. 83), which appear to give good results.

It is evident, however, that no form of furnace can resist overheating when covered by a non-conducting deposit of salts, or mineral oil.

Though not much used in France, other methods of strengthening furnaces may be noticed. The furnace may be strengthened by external plate, or angle-iron rings, with distance pieces from 1.2 to 1.6 ins. in thickness (Figs. 84 and 85). These are fixed to the furnace by round-headed bolts, with nuts and washers on the outside. The rings

are similar in section to the bridges in common use for supporting the crown of the combustion-chamber. The furnace may be constructed of short lengths of different diameters fastened end to end.* None of these systems appear to afford the security of the Fox or Purves corrugated furnace, provided their corrugations are properly designed, as it is a *sine quâ non* that the number of riveted joints directly exposed to the fire should be reduced to a minimum, and corrugated furnaces fulfil these conditions.

The mode of riveting the furnaces to the end-plates is a part of the construction of a boiler that requires the

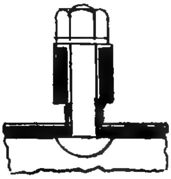


Fig. 84.

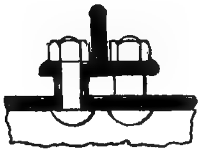


Fig. 85.

greatest care and skill; local straining may become excessive, and the slightest leaks give rise to rapid deterioration.

In construction, the furnace is first fixed to the combustion-chamber, which is then attached to the body of the boiler. Usually, the upper part of the furnace is turned up, and riveted to the tube-plate on the side away from the fire. The shape of the bottom-plate enables the turned-up edge of the upper part of the furnace to be introduced into the combustion-chamber with ease (Fig. 86). This arrangement has the advantage of not exposing the edge of the plate directly to the flame. As overheating is not the greatest danger to which the joint is exposed, it being subject to irregular heating and cooling, the contrary arrangement shown in Fig. 87, is sometimes adopted, and is more convenient for repairs. It is

* See Seaton's "Manual of Marine Engineering," p. 455 of the 15th Edition, 1904.

advisable to employ a thin firebrick lining to protect the joint between the top of the furnace and the tube-plate.

The form of joint at the combustion-chamber end allows of a good accurate joint being made; but at the front end of the furnace, where two cylinders have to be slipped one into the other, it is necessary to leave a play of $\frac{3}{32}$nds of an inch all round, and subsequently to expand the furnace to fit the shell. Fig. 88 shows how, in practice,

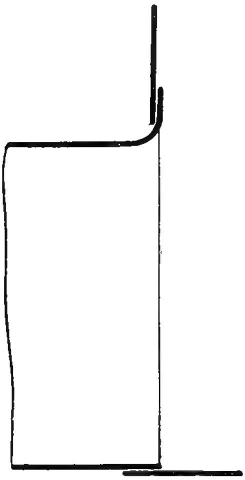


Fig. 86.

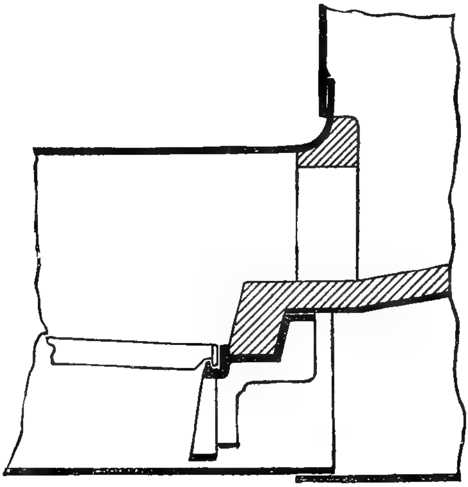


Fig. 87.

there is a risk of this fit being confined to the front edge of the furnace. To ensure a perfect fit, the collar, formed by turning over the front-plate, should be coned so as to allow the furnace, which becomes coned when expanded, to bear all round (Fig. 89). Another plan, which is pretty generally favoured at the present time, is to turn the edges of the front-plate outwards (Fig. 90); this facilitates the stiffening of the furnace, and also the riveting (especially when hydraulic riveters are used). This arrangement is, however, less satisfactory than the preceding one as regards the tightness of the joint when

under pressure; it is evident (Fig. 90) that the interior pressure tends to separate the two lips of the joint, whilst, in the form shown in Fig. 89, it assists and sustains the tightness of the interior edges.

The expanding of the furnace ought always to be done cold, especially if the plates are of steel, as local heating impairs the quality of the steel.

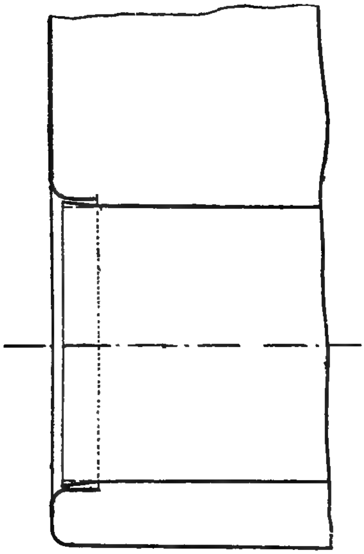


Fig. 88.

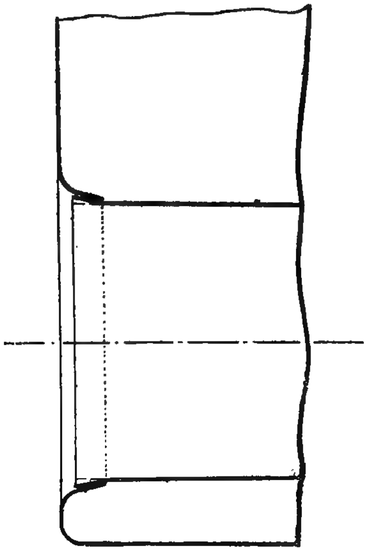


Fig. 89.

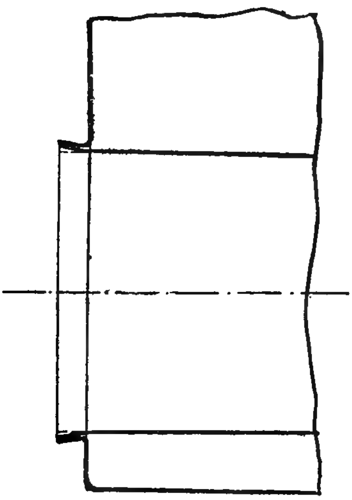


Fig. 90.

Well-constructed furnaces made of high-class material will last as long as the shells of the boilers. When made of iron plates, they are subject to local damage occurring at the crown, due to the lamination of the plates. In order to make

these good, the blistered part is cut out, and a patch is riveted on. In corrugated furnaces, the patches are cut from a plate with similar corrugations. Furnaces as now made of steel are almost entirely free from this form of weakness.

90. *Combustion-Chambers.*—Every combustion-chamber is made up of two flat ends and of a shell, the shape of which varies a good deal according to the different type of boiler. The two end-plates are usually turned over to form the joint; but this is not an invariable rule. Of the six sides of the chamber, the first, that is, the front-plate, is kept in position by the tubes; the second, or crown-plate, is fixed in a special manner; the other four form sides to water-spaces, and these will be described first.

The water-spaces, composed of flat sides, from 6 to 8 ins. apart, are well able to stand any pressure at present in use, owing to the ease with which they can be stayed. The stays are screwed at both ends, and the holes are tapped in place, thereby forming a very rigid structure.

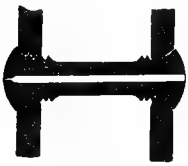


Fig. 91.

In some boilers, especially on those of torpedo-boats of the locomotive type, these stays are made hollow, so that should any of them become rusted through, or broken, attention would be drawn to the fact by the escape of steam. On the furnace side, the hole in the stay is very small, thereby reducing the quantity of steam that can escape, and avoiding any back rush of the flames through the furnace doors.

The stays are spaced about 8 ins. apart; this is sufficient to obviate any appreciable buckling. They are about $1\frac{3}{16}$ ins. in diameter, and the stress, under a pressure of 170 lbs. per square inch is, therefore, about 3 tons per square inch. The finer the thread, the greater the strength of the bolt under the thread. This is not made less than

about $\frac{3}{32}$nds, for fear of stripping, should the thread become rusted. In addition to the thread, stays are now fitted with nuts on both ends, as shown in Fig. 92, illustrating the form of stay used in the boilers of the *Savoie* and *Lorraine*; this precaution makes the stay itself tight, but does not dispense with the necessity for tapping the plates, which alone ensures the tightness of the joint as a whole. In combustion-chambers, care must be taken not to use any red-lead under the head and nuts of the stays; these will then be better able to transmit heat, and consequently less liable to become over-heated.

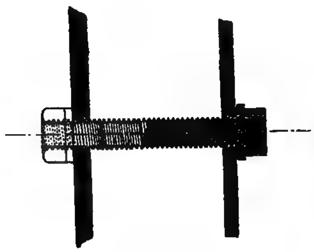


Fig. 92.

For a long time it was considered sufficient simply to screw the stays. The stay, after being screwed up in position, was turned over and riveted. The head thus formed, though less liable to overheating, and less exposed, than the present heads and nuts, reduced the tightness of the joint to that of the thread.

When buckling begins, only the outer threads at either extremity of the stay have any grip; this is more particularly the case with fine threads. Fig. 93 is an exaggerated example of the effect produced. Some boiler explosions due to this cause occurred prior to the introduction of nuts and heads.

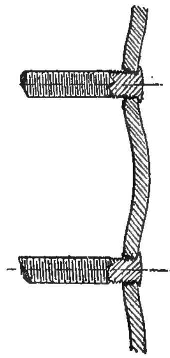


Fig 93.

The stays are better fitted with a nut at either end, because, if provided with a head at one end they are apt to leak. A circular washer projecting beyond the nut is sometimes added to secure greater tightness.

The stays in compression are always spaced more closely together than those in tension, and by giving the

plates more support, enable the thickness of the plates to be reduced; but they obstruct the circulation of the water, and may, owing to their small distance apart, cause the deposits formed round them to run together and become continuous.

The staying of the tube-plate will be gone into when the tubes and tube-joints are under discussion.

The crown of the combustion-chamber, which cannot conveniently be stayed from any neighbouring plates, is

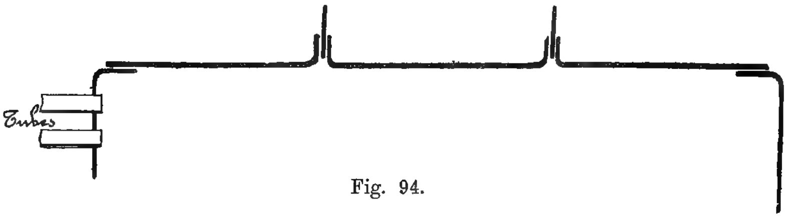


Fig. 94.

subject to high temperatures, and demands special care, as it is the first place in the interior of the boiler to become uncovered should the water-level drop; above all things, any staying, by means of plates and angle-irons, necessitating the doubling of the plates, and the consequent danger of overheating, must be avoided.

The crown-plates of the combustion-chamber have sometimes been constructed of narrow plates with their edges turned over, and with a vertical ring between them, in a similar manner to the plan adopted in furnaces (Fig. 94). They have even been made of corrugated plates. These complicated arrangements have not found favour, although presenting an important advantage, viz., that of allowing for expansion without any deformation of the end-plate, or unduly stressing the tube-joints.

On the *Forbin*, which was fitted with small lead distance-pieces or gauges, a flattening of 0.04 in. was noticed in the ring fitted to the crown plate of the combustion-chamber,

and buckling in the furnaces to the extent of $\frac{3}{4}$ in. to 1 in. has been observed. Fig. 95 gives a sketch of the combustion-chamber of the *Marceau*, which is similar to that of the *Forbin*.

In some cases it has been considered sufficient to

MARCEAU.

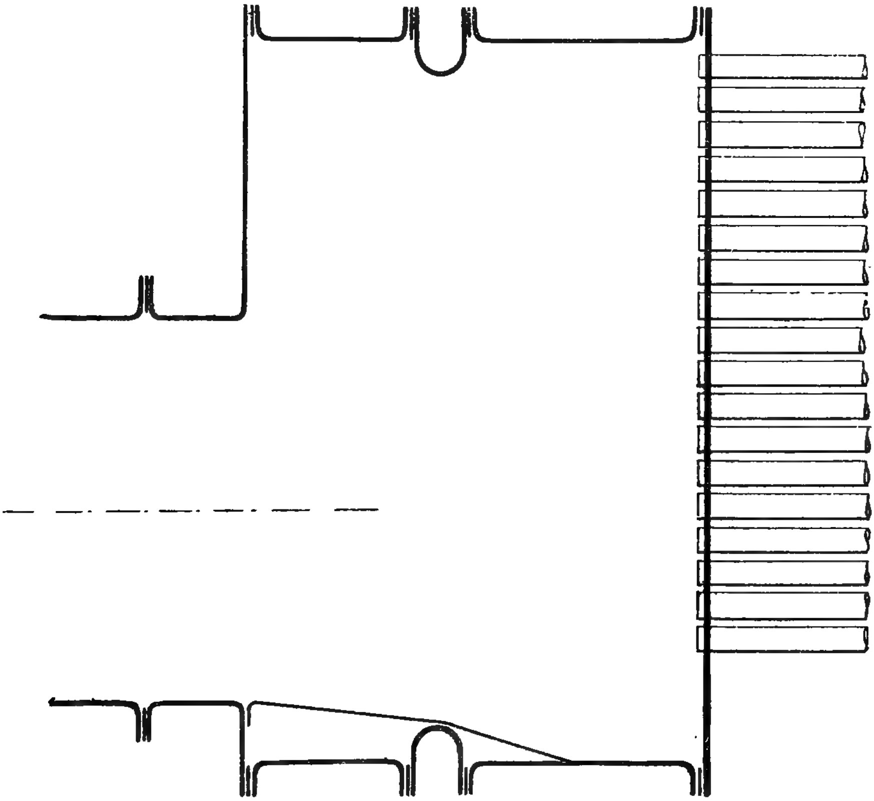


Fig. 95.

suspend the crown of the combustion-chamber to the shell of the boiler by stays or bolts, screwed into the crown of the combustion-chamber, and fitted with lock-nuts. As these stays expand more than the boiler-shell, and as

the combustion-chamber also expands, the stays commence by compressing the crown, and do not support the same until bulging under the steam pressure begins to take place. A certain well-founded mistrust has arisen, which

SFAX.

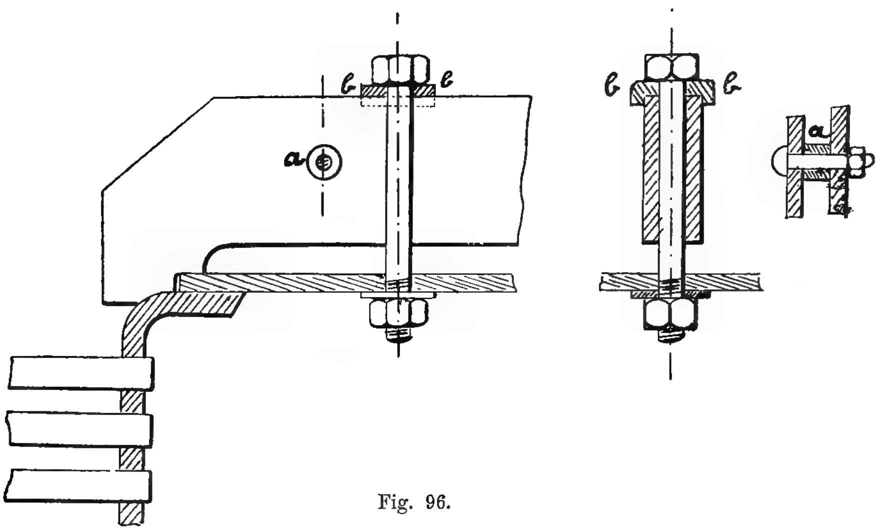


Fig. 96.

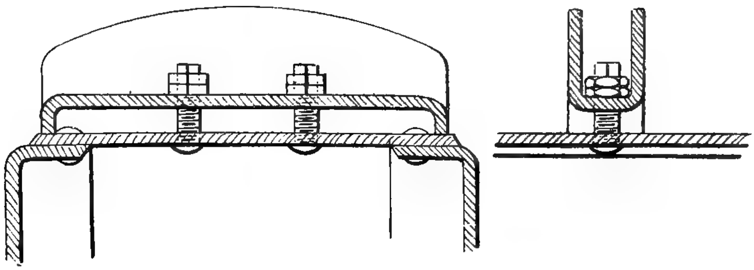


Fig. 97.

was further increased by the accident that happened, in September, 1894, to the crown of a locomotive type boiler on torpedo-boat No. 120. Owing to shortness of water the crown bulged, breaking one of the stays, and causing the neighbouring ones to give way in succession.

The most usual arrangement is to support the crown of the combustion-chamber by means of crossbars, clear of the plate, and bearing on the top of the front- and back-plates of the combustion-chamber. To these cross-bars or bridges are hung bolts at suitable distances. The form or design of the cross-bars varies; sometimes they are made of a solid cast-steel plate, thickened where the bolts pass through; more often they are composed of two plates, between which pass the bolts (Fig. 96). The

CÉCILE.

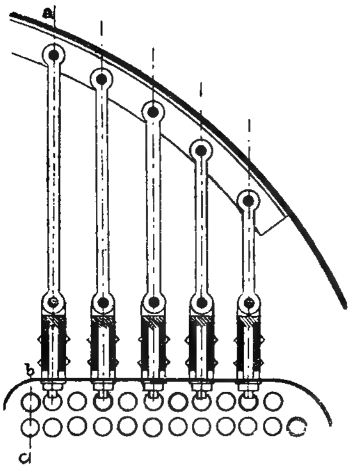
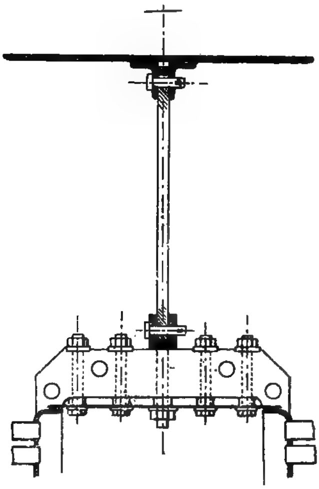


Fig. 98.

Section on *a b c*.



Combustion-chamber.

Fig. 98A.

two plates are kept from spreading by distance-bolts, as at *aa*, and by small cross-plates, with edges turned down, as at *bb*, on which the heads of the bolts rest. The cross-bars or bridges are sometimes simply plates bent into the shape shown in Fig. 97.

The bars or bridges act as rigid girders, transmitting to the back- and front-plates the whole of the pressure on

the crown. To relieve these end-plates, the systems of bars, and stays from the shell, have sometimes been combined, as, for example, on the *Cécile*; but this involved the same drawbacks as attended the use of furnace crown-stays (Fig. 98).

Fig. 72A shows a combustion-chamber, in which the shape of the crown assists in resisting compression.

All the foregoing illustrations are taken from return-tube boilers.

In direct-tube or Admiralty type boilers, where the crown of the combustion-chamber is very close to that of the furnace, and consequently exposed to great heat, the exercise of still greater care in their construction is necessary.

91. *Various Types of Boiler Tubes and their Spacing.*—Boiler tubes receive the hot gases as they emerge from the combustion-chamber, and it is by their means that a large portion of the heat is transmitted from the fire to the water. Generally speaking, the longer and smaller they are, the better do they fulfil their duty of cooling the flames; the question of their length and diameter is, therefore, intimately connected with that of the efficiency of the boiler. It will be sufficient, for the present, to state that, in practice, their internal diameter varies from 2 to $3\frac{3}{8}$ ins., and that the tendency in the French Navy, on the abandonment of cylindrical boilers, was to use small diameters.

In regard to construction generally, the important points to be studied are the quality of the metal, the spacing of the tubes, and the type of tube-joints.

Boiler tubes are made of iron, of steel, or of brass.

Iron and steel tubes are cheaper than brass ones, and, as regards the transmission of heat, are in no perceptible way inferior to the latter. With a thickness of $\frac{3}{32}$nds of an inch, which is that given to brass tubes, they last well,

say some three or four years in boilers in constant use. At the present time they are almost the only ones fixed on passenger vessels. Much discussion has taken place on the relative merits of iron and steel tubes, without any very definite conclusion being arrived at. Tubes of rather hard and tough steel possessed this advantage, that they could be taken out without loss of shape and replaced when the ordinary conical mandrel was used to expand them; but, at the present time, owing to the "Caraman" system being employed, the tubes are so accurately fitted in place that they have to be split to remove them, and cannot be replaced until fresh ends have been welded on.

Steel tubes are electro-negative in the presence of iron, and should have, on that account, a shorter life than iron tubes, as galvanic action, according to some authorities, is said to take place.

Iron tubes sometimes have copper ends welded on to them in order that the expansion, which increases with the temperature, may increase the tightness of the joint. This practice, which obtained mainly owing to the employment of copper fire-boxes, is now being discontinued.

The great disadvantage of brass tubes is their price, and, moreover, that at a temperature of about 400° Fahr. they lose a good deal of their strength. Their long life is their chief recommendation; if made of very homogeneous metal they may last out several boilers by being simply re-ended with brass or copper. They have also the enormous advantage of not deteriorating when the boiler is laid up, during which time iron or steel tubes are liable to become pitted and perforated; this last quality renders them peculiarly valuable for use on warships. Further, brass tubes do not give rise to any injurious galvanic action, and their greater expansion does not seem to have any bad effect on tube-joints. On the *Condor*, iron was used for the stay-tubes, and brass for the ordinary tubes,

without any injurious effect on the tube-plate being noticed.

At the time the use of cylindrical boilers was discontinued in the French Navy there was some difference of opinion as to the best material to be employed for the tubes. For instance, on the *Isly* they were of brass; on the *Davout*, *Cécile*, and *Wattignies*, of steel with copper ends; and on the *Hoche* and *Marceau*, of steel alone.

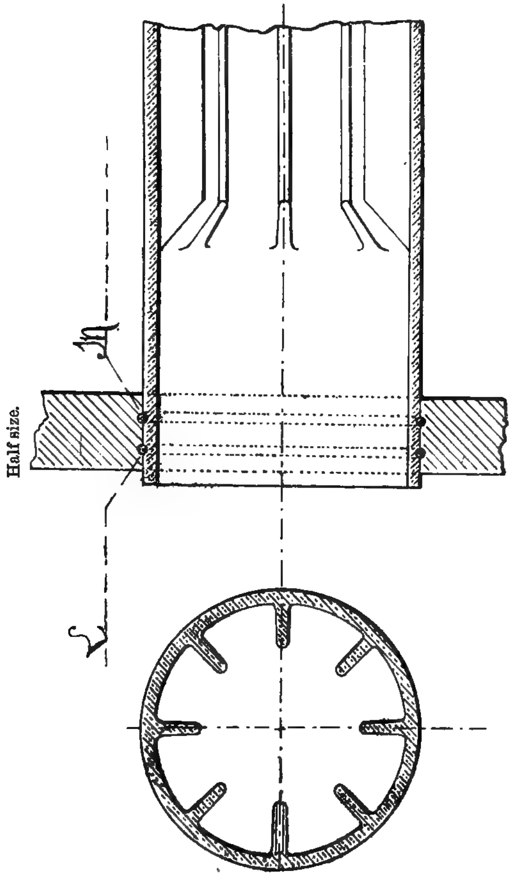
The most unfavourable instance of steel happened on the *Marceau*, where the tubes were found to be badly pitted at the end of the trial voyage to Cronstadt. Since that time, as the precaution has been taken to keep the boilers full of water, slightly alkaline, both iron and steel tubes have lasted longer. On merchant vessels, iron or steel is preferred as being less costly; nevertheless, on some American boats they have come back to brass tubes.

The introduction of solid drawn steel tubes, manufactured from bent plates or hollow ingots, has given a considerable impetus to the use of steel, the employment of which tends to become general. In the early stages the question of price largely hindered its general introduction. The mildest quality of steel is the best, say with a breaking strength of 25 tons per square inch; hard steel is inferior to iron. Steel containing 25 per cent. of nickel, which is not affected by sea-water, would form a satisfactory solution of the problem were it not for the difficulty experienced in working it.

In order to increase the area of metal in contact with the hot gases, tubes with internal ribs, or Serve tubes, have been employed, of which sections are given in Fig. 99. With the same diameter, Serve tubes have a heat-absorbing surface 75 per cent. greater than that of ordinary tubes, while the exterior heat-distributing surface remains the same. After many years' experience with Serve tubes on several steamship lines, it has been

found that more work is got out of the boiler, resulting in an economy in the consumption of coal per horse-power of 10 per cent.

The ribs of the Serve tubes are stopped within about



M. German Silver. L. Brass.

Fig. 99A.

Fig. 99.

12 ins. of the end, to enable a conical Dudgeon, Caraman, or other expander to be used. (Fig. 99A.)

The resistance to bending offered by the Serve tubes has given rise to a fear that their rigidity would cause an excessive strain on the tube-plates. Though during a trial

on the *Fleurus* they caused leaks in the tube-plate, on merchant steamers, on the other hand, according to Mr Ellis, they have been at work under forced draught for several years without being the cause of any trouble; further, on the American locomotives to which they have been fitted, the result was an actual diminution of leaks in the tube-plate.

In tubular boilers the ribs of the Serve tubes are situated where the transmisson of heat takes place with the greatest difficulty, hence their efficiency. In tubulous boilers the contrary is the case, and the ribs are of little practical value.

The Guébhard spirals or retarders consist of thin strips of brass twisted into the form of a screw, and when used, are placed inside the tubes. They agitate the gases, causing all the particles to come successively in contact with the sides, without in any way altering the heat-absorbing surface of the tube.

Tubes have sometimes been given a slight initial set or curvature so as to render them flexible and capable of taking up expansion without injury. This arrangement, which is inapplicable to stay-tubes, though it seems reasonable at first sight, does not appear to have been advantageous in any way.

There are two ways of grouping the tubes, one in zigzag, as shown in Fig. 100, the other in parallel lines, as in Fig. 101.

The latter allows of a greater number of tubes, in the proportion of $\sqrt{\frac{4}{3}}$ or 1·15 to 1, and at the same centre to centre distance, consequently, with the same width of plate between each hole. This arrangement was preferred for a long time, as to obtain the greatest possible heating surface was the only object aimed at, and this caused the tubes to be placed as close together as possible, consistent with the exigencies of construction. Later, more attention was paid

to ensuring the escape of the steam bubbles, and at times the tubes were placed farther apart, although some of the benefits of the zigzag arrangement were thereby lost. The rectangular position facilitates the escape of the steam bubbles, the circulation, and consequently the transmission of heat, and is more favourable for cleaning the exterior of the tubes.

As examples of the zigzag arrangement may be mentioned the boilers of the *Marceau* and of the *Davout* (Admiralty type), as also the cylindrical return-tube boilers which were the orthodox type in 1877. Fig. 100 represents

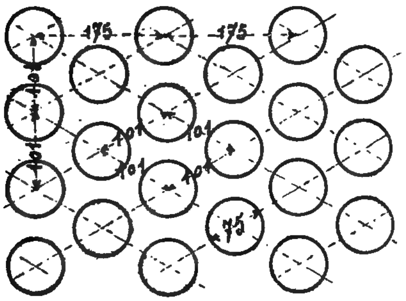


Fig. 100.

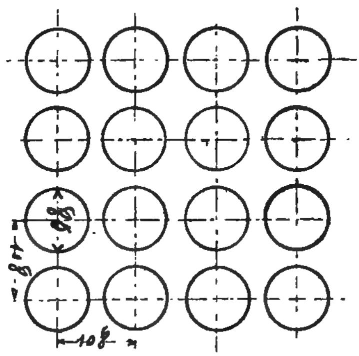


Fig. 101.

the spacing of the tubes of one of these boilers; the external diameter of the tubes is 3 ins. ($2\frac{3}{4}+\frac{1}{8}\times 2$), the distance, centre to centre, is 4 ins., which leaves 1 in. of plate between each tube. In the *Cécile* (double-ended boilers), the *Hoche* (Admiralty type), the *Goëland* (return-tube), and others, the rectangular arrangement was adopted (Fig. 101). On the *Goëland's* boilers the tubes are $3\frac{3}{8}$ ins. outside diameter ($3\frac{1}{8}+\frac{1}{8}\times 2$), and are $4\frac{1}{4}$ ins. centre to centre, which only leaves $\frac{7}{8}$ in. of plate between them.

The predominant advantage of a good circulation having been now recognised, the rectangular arrangement is generally preferred at the present time. It is even the

practice at times to omit a row of tubes vertically over the centre of each furnace in order to facilitate the escape of the steam bubbles formed on the furnace, and which appear to constitute about one-third of the total steam produced.

On the *Sfax*, where this row of tubes was subsequently removed, it was proved that the priming which took place prior to this being done was thereby entirely stopped.

In America, where only the rectangular arrangement is used, the tubes are placed further apart horizontally than they are vertically. Thus, on the *Minneapolis*, tubes of $2\frac{1}{4}$ ins. external diameter are spaced 3 ins. centre to centre vertically, and $3\frac{3}{4}$ ins. horizontally.

It will be seen that the tubes cut up the tube-plates until only a third, or even a quarter of their original section is left; but it is not such an important source of weakness to the boiler as the presence of the furnace itself.

92. *Tube-joints and their Protection.*—The joint between the tubes and the tube-plate is one of the most intricate subjects in connection with cylindrical boiler construction, and demands the most careful consideration.

Formerly, when temperatures did not exceed 250° Fahr., and when pressures did not exceed 30 lbs., when, moreover, forced draught was unknown, the holes in the tube-plate were left $\frac{1}{16}$th larger than the tubes themselves, which were by no means always perfectly round. The tube was first inserted, and was then expanded, by a conical drift driven in with a sledge hammer; and the tube kept in place by a slightly conical ferrule, driven into position so as to keep the tube from contracting. On warships the tube was riveted over on the outside, as shown in Fig. 102, but only at the combustion-chamber end.

By this means tight joints were obtained at a comparatively small cost, and the joint was so good, that some engineers were of opinion that stay-tubes were an un-

necessary precaution. During this period several kinds of removable or dismountable tubes were successfully employed.

With the rise of temperatures in the steam, and especially with the intensity of combustion accompanying forced draught, tube-joints began to give way everywhere. Leakage from the joints rusted the plates, gave rise to what is known as "bird's nesting," and obstructed the tubes; the leaks became, in many cases, so serious that they formed regular streams falling into the ashpan and thence into the stokehold. Here they occasioned more alarm than actual harm, but at the same time necessitated, for the sake of prudence, the immediate lowering of the fires. In some cases this loosening of the joints became a very serious evil, for the escape of steam was strong enough to drive the fires back into the stokehold, even against a forced draught. Luckily, the tubes have always a tendency to protrude through the tube-plate instead of withdrawing themselves.

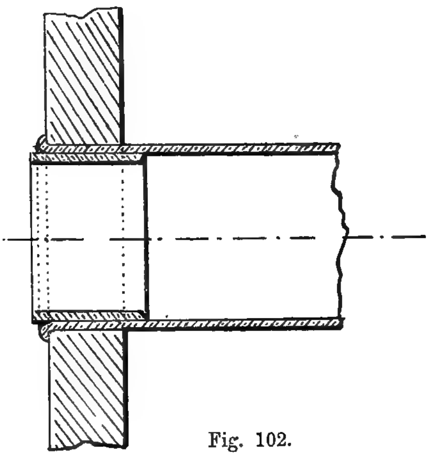


Fig. 102.

To improve the joint of the tubes with the tube-plate, the Dudgeon roller-expander was introduced, which, bearing only on three points at a time, was much more powerful than a mandril, which bears all round simultaneously. Thus it became possible to form a shoulder close up to the tube-plate (Fig. 103), an arrangement adopted mostly on stay-tubes. The Dudgeon expander was improved upon by M. Caraman, who placed rollers obliquely to the axis of the

mandril, thus forming a self-feeding expander, with which a very large expanding force can be exerted. M. Caraman also uses two circular grooves in the thickness of the tube-plate into which are inserted two rings, one of brass wire and the other of German silver, the pressure of the mandril forcing them into the metal of the tube (Fig. 104). When the Caraman process is used, there is no occasion to have copper ends on the brass tubes of torpedo-boat locomotive boilers, and stay-tubes may be altogether dispensed with. Tubes expanded on the Caraman system are never riveted over

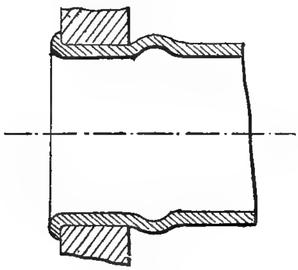


Fig. 103.

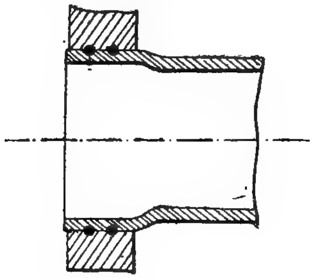


Fig. 104.

the tube-plate, as the hammering would destroy the effect of the Caraman expander.

By these means tubes can be kept tight under the most intense combustion, provided always that the firing is regular. Many successful four-hour trials have been carried out with tubes expanded on the Caraman or the Dudgeon systems while burning 40, 50, or even 56 lbs. of coal per square foot of grate per hour. To ensure an entire absence of leaky tubes it is not sufficient that they should be expanded by skilful workmen, but the firing also must be done by practised hands, especially in direct-tube boilers, whether of the cylindrical or of the locomotive type. The slightest irregularities during firing, such as a furnace door kept open too long, or local thinning of

the fire on some part of the grate, giving rise to indraughts of cold air, are often fatal to the tightness of the tubes. The changing of the stokers at the end of each watch is always a critical moment.

All said and done, the perfect tube-joint has yet to be discovered. Ordinary tubes have been screwed similarly to stay-tubes, but the improvement does not warrant the extra cost. Attempts have been made lately electrically to weld steel tubes to the tube-plates, and this may turn out to be a solution of the difficulty when this class of work has been further perfected. Finally, attempts have been made to overcome the primary cause of the accidents, which may be briefly described as follows.

The principal cause of injuries to tube-joints appears to be the great difference of temperature existing between the tube-plates and the tubes themselves. The thickness of the tube-plates is sufficient to raise the fire side of the plate to a temperature of 180° Fahr. higher than that on the water side of the plate. In addition, under brisk firing, the plate is kept from direct contact with the water by a compact swarm of bubbles, forming a layer of steam behind the tube-plate, while the tube-end, always cooled by conduction, cannot become much hotter than the body of the tube, which is surrounded by water. The tube-plate may, therefore, attain a temperature of 750° or even 850° Fahr. round a tube whose temperature is only 480° or 580° Fahr. at the most. The hole may therefore become $\frac{6}{1000}$ths of an inch larger than the tube (supposing it to be of the same material as the plate), and the joint becomes unreliable, however great may have been the pressure originally produced by the expander. Under these conditions the joint is bound to give way should any cooling of the gases occur, for the tube would be affected by it long before the plate.

The failure of a tube-joint is almost always attended

by a slipping of the tube in the plate, due to longitudinal expansion; this, and the pressure of the steam acting on the tubes, have not so far been taken into consideration. When the boiler cools, the tubes come back into place, and the boiler may seem tight even under hydraulic pressure, but directly it is put under steam again the leaks reappear. It is necessary, therefore, to lessen as far as possible the difference of temperature between the tubes and the tube-plate. Many means have been tried in order to attain this end.

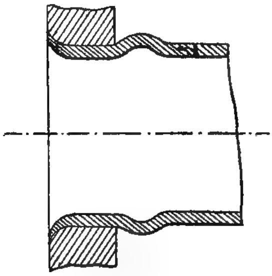


Fig. 105.

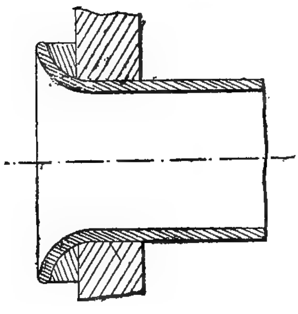


Fig. 106.

On the steamers of the Russian firm, Nobel, which run on the Volga and the Caspian Sea, and which are fired with petroleum, good results have been obtained by avoiding all projection of the tubes beyond the tube-plate, and by turning over the end of the tube within the thickness of the tube-plate (Fig. 105). The stay-tubes, the nuts of which used to burn as badly as the old rivet-heads, were given up, as were also the nuts and washers on the stays.

In America, the tube-ends have sometimes been projected beyond the tube-plate, and the ends have been turned over a ring of triangular section, as shown in Fig. 106, whereby it was expected that the temperature of the tube-end would be raised.

In England, on the contrary, the edge of the plate next to the tube has been protected from contact with the fire, thereby keeping down its temperature. After trying an earthenware ring for the purpose, one of malleable cast iron

was designed. These ferrules are shown in Fig. 107, several different varieties of which have been brought out.

This class of ferrule has also been used in France. Those fixed to the boilers of the *Fleurus* are shown in Fig. 108. It will be seen that the tubes of the *Fleurus* are screwed into the tube-plate. This screwing gives a bad metallic contact and renders the changing of a tube almost an impossibility due to the enlargement of the hole in making good the thread.

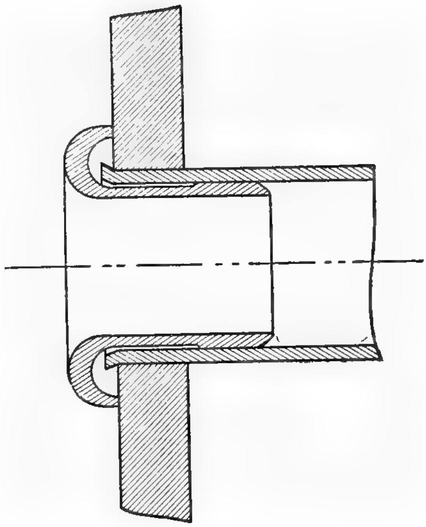


Fig. 107.

The result of all this investigation, and of the various attempts to avoid the danger of injury to the tubes at the joints, is that forced draught has been almost entirely abandoned, as mentioned on page 79, which means that only half the heat which could be produced and transmitted to the water through well-designed tubes is now available in marine boilers, or only a quarter of the heat which the boilers of locomotives will support without injury in the hands of skilful stokers. This want of adaptibility to forced draught, owing to the weakness of the tube-joint, places tubular boilers at a serious disadvantage in comparison with tubulous boilers with accelerated circulation.

The foregoing precautions, though inefficient as joint-tightening devices at the combustion-chamber end, are, on the other hand, superfluous at the smoke-box end. The hole is bored from 0.04 to 0.08 in. larger in diameter

than the tube, and it is only necessary to expand the tubes well to ensure a tight joint. By heating the air supplied to the furnace, the access of cold air currents to the tubes is prevented and the risk of leaky tube-joints is diminished.

93. *Stay-tubes.*—So far, only ordinary boiler tubes have been dealt with, viz., those intended for the passage of hot gases, and not specially designed to act as stays to the tube-plate, though they do so to a certain extent.

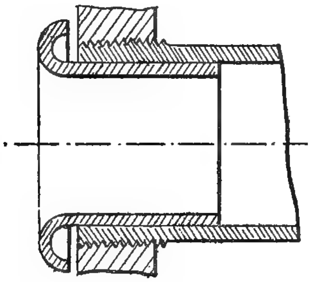


Fig. 108.

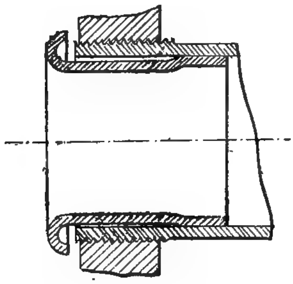


Fig. 109.

Mention must, therefore, be made of stay-tubes, which, in some instances, have been dispensed with in the mercantile marine, while the use of the Caraman system tends to render their employment unnecessary in the navy.

Stay-tubes are intended to keep the two tube-plates at a fixed distance apart. They are generally made of the same material as the others, but of double the thickness; this increase of thickness is not followed by an increase in the expansion, or any undue straining of the tube-plates.

Formerly, stay-tubes were held in position by two nuts on each side of the tube-plate. The present practice is to tap the plates, and nuts are no longer necessary except as lock-nuts. A single nut, or even the riveting over of the tube-ends, is therefore found sufficient. The ends of the stay-tubes are thickened about $\frac{1}{16}$th of an in., so as not

to be unduly weakened by the threads. Fig. 70 shows the distribution of the stay-tubes in the boilers of the *Savoie* and *Lorraine*.

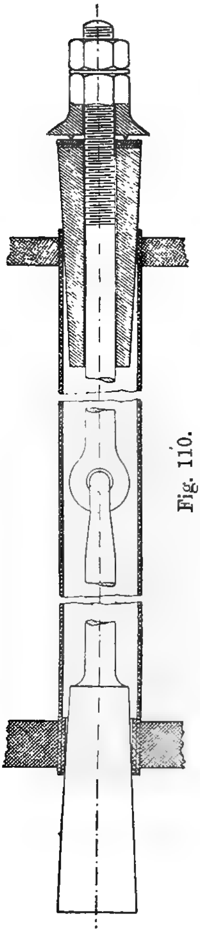


Fig. 110.

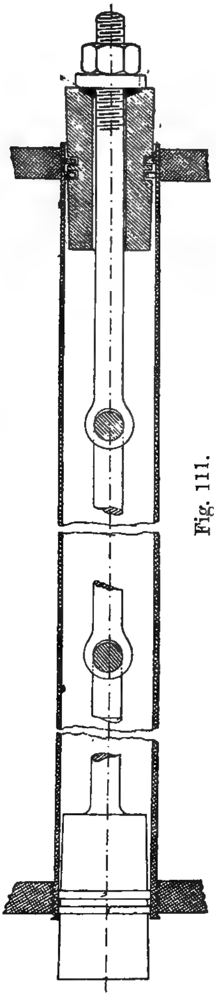


Fig. 111.

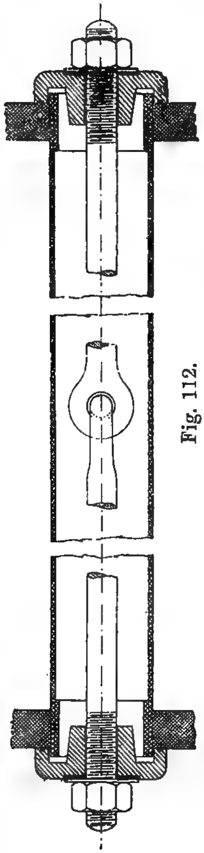
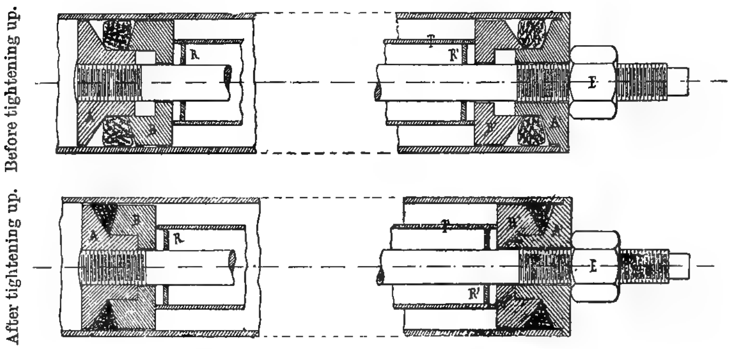


Fig. 112.

94. *Tube-stoppers.*—It sometimes happens, when boilers are under pressure, that leaks occur in the body of the tubes, either through pitting, defects in the welding or

drawing, or by a transverse crack where the tubes have been re-ended. Formerly, when this occurred, fires were at once drawn, and if there were not time to make immediate repairs, the two ends of the damaged tube were stopped with conical wood plugs driven hard home.

These wooden plugs had an uncertain hold, even in the times of low pressure. With the pressures now in vogue, they are useless. The tube-stoppers at present



Figs. 113 and 113A.

employed are joined together by a tie-bar, which may be in one or more pieces. Figs. 110, 111, 112 show three different kinds of these.

The first two have a wedge action, and the last makes a tight joint by a pressure on the tube-plate itself. In all three cases, as the plugs are inserted at the combustion-chamber end, it is necessary in each case to draw the fires.

To allow of plugging without drawing the fires, M. Houille, an engineer in the French Navy, has invented a tube-stopper, with stuffing-boxes at either end, shown in Figs. 113 and 113A.

The joint is made by means of asbestos rings pressed between two metal blocks A and B, which force the plastic material against the sides of the tubes. The front

packing is held in place by the hollow tube T, which is kept central by the rings R R. When the screw E is tightened up, the asbestos is flattened simultaneously at both ends of the tubes.

Another tube-stopper, which obtains the same results by simpler means, but at the loss of some tightness, is that of M. Latil, shown in Figs. 114, 114A, and 114B. It consists of a rod, at the end of which is hinged a folding plug, that can be passed through the tube, and which opens out or unfolds in the combustion-chamber when pulled into position. At the smoke-box end an india-rubber washer, pressed between two metal washers, affords temporary protection while the plug is being fixed in position. The fixing of the whole apparatus takes about five minutes.

Tubular boilers have a great advantage over tubulous boilers in that it is possible to plug the tubes of the former without emptying the boiler, while with the latter this is impossible.

95. *Smoke-boxes and the Dangers attendant upon too sudden Cooling.*—On leaving the tubes the gases of combustion enter the smoke-box, which is a casing attached to the face of the boiler, from whence they pass into the funnel.

In the smoke-box, facing the tubes, is a large opening, closed by a double-flapped door, for the purpose of cleaning or sweeping the tubes. This operation, which has been described in paragraph 48, is not only very trying to the men and detrimental to the boiler, but also interferes with the draught, as, directly the smoke-box doors are open, the air from the stokehold takes a short cut to the funnel. Before cleaning the tubes, fires should be damped to avoid lowering the temperature too suddenly.

The cleaning process should be done as smartly as possible, and taking each boiler in succession. In some

cases the smoke-box has been divided up so as to correspond to the number of furnaces. Only one furnace

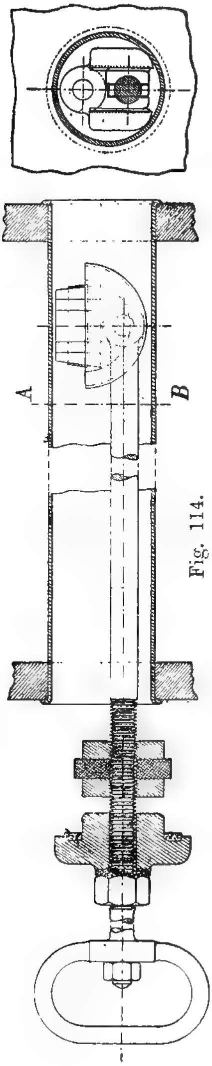


Fig. 114.

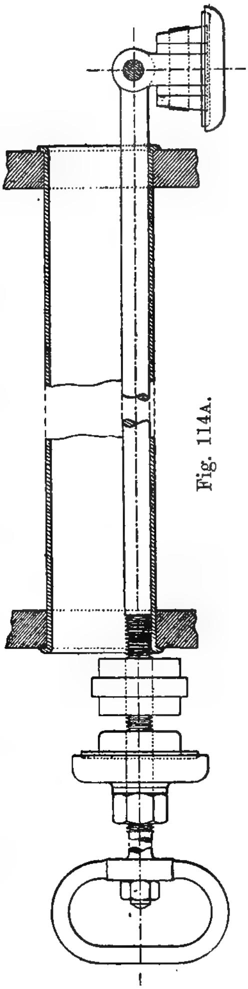


Fig. 114A.

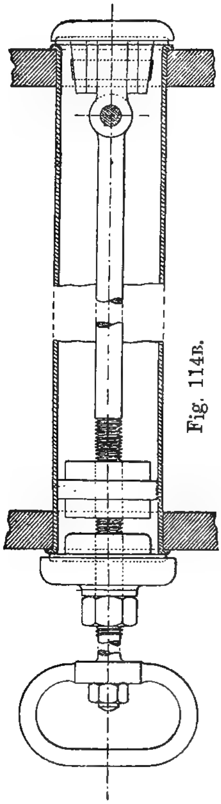


Fig. 114B.

at a time is thus put out of action, and, what is more important, with forced draught the furnaces are in-

dependent of one another. In these cases a damper R is fitted into each division of the smoke-box A, and prevents any indraught of cold air through an open door, which would check the general draught of the chimney (Fig. 115). This sensible, though rather complicated, arrangement has not found much favour.

Should the engines be suddenly or unexpectedly stopped the noisy blowing-off from the safety-valves can usually

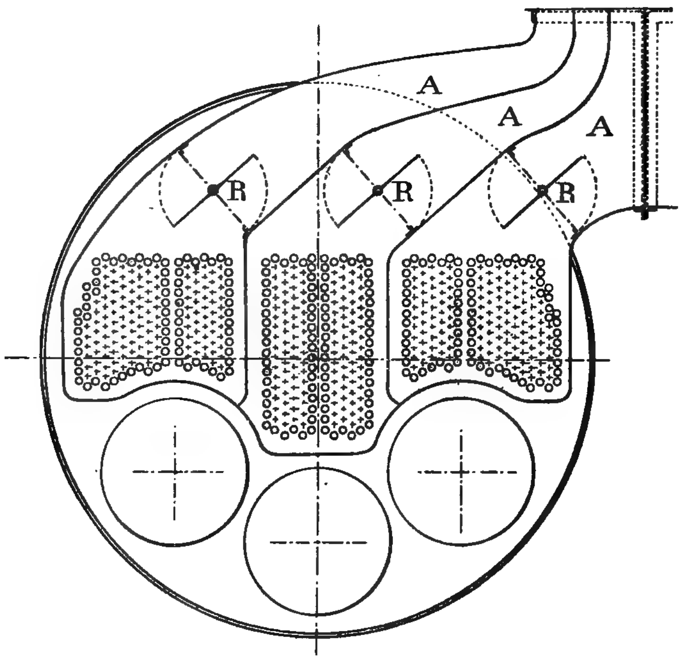


Fig. 115.

be checked by opening the smoke-box door. This proceeding, which for a long time used to be practised with the greatest recklessness, should be most strictly prohibited on tubular boilers, on account of the strains to which it subjects a boiler when steaming hard. The terrible accident to the boiler of the *Revanche* must not

be forgotten, where, through the opening of the smoke-box doors, the steam dome suddenly gave out.

At the present time the smoke-box, like the funnel

Fig. 116A.

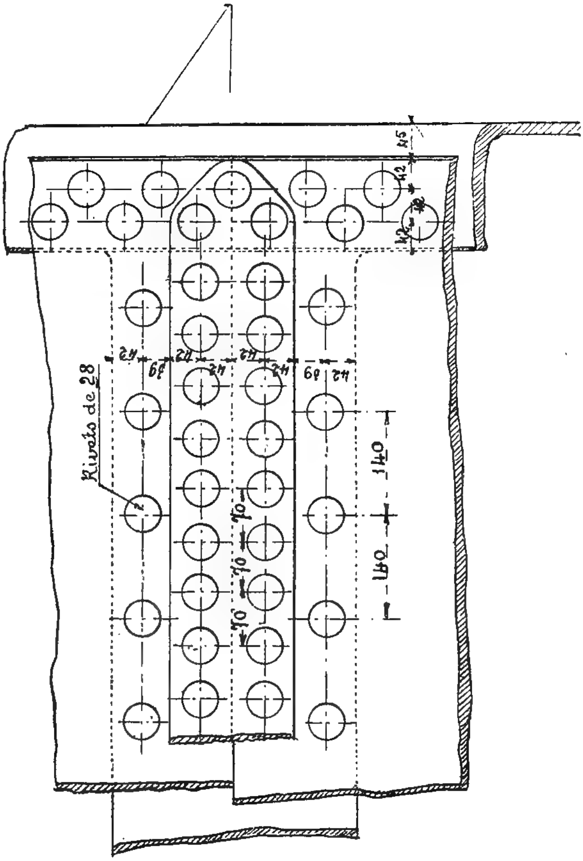


Fig. 116.

REDOUBTABLE.

EXAMPLE OF A LONGITUDINAL BUTT-JOINT IN A BOILER SHELL.

and uptake, is not made an integral part of the boiler proper, but is simply attached to it. This used not to be the case on rectangular boilers, where the top of the

smoke-box passed through the steam space, and the abandonment of this arrangement has very much simplified boiler construction.

KAISER WILHELM DER GROSSE.

EXAMPLE OF A LONGITUDINAL BUTT-JOINT IN A BOILER SHELL.

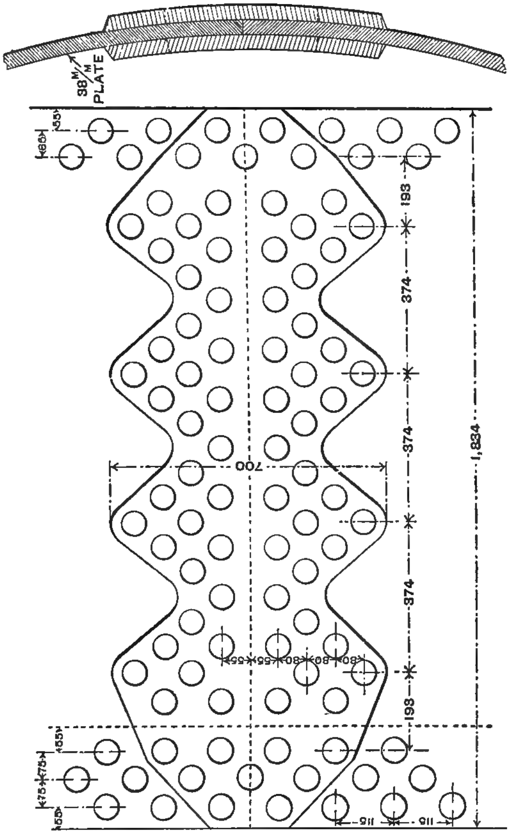


Fig. 117.

96. *Boiler Shell.*—The various internal parts of the boiler just described, being heated on one side by the products of combustion, and being on the other side in contact with the steam and water, are in compression. The boiler shell, which is exposed to the atmosphere on the one side and to the steam and water on the other, is in tension.

The boiler shell is composed of two parts, the one

cylindrical, which constitutes the shell proper, and the other flat, namely, the front and back.

The shell is the most important part of the boiler, and has to bear the greatest strains. It is the only part where the strains can be estimated even approximately or where any comparison with those existing in other boilers can be established. In tubular boilers the stress on the shell-plates limits the pressure at which the boilers can be worked. Fifteen years ago the thickest iron boiler plates made were $1\frac{3}{16}$ths ins., while in steel they are nowadays made up to $1\frac{3}{8}$ths or $1\frac{7}{16}$ths ins. or even higher.

Particular attention has been paid to the longitudinal seams of the shell, in order to give them at least 80 per cent. of the strength of the solid plates, and they are nearly always butt-jointed, with double butt-straps. There are generally four or six rows of rivets, two or three on either side of the seam, every alternate rivet being usually omitted in the outside rows. The size and spacing of the rivets is determined according to the usual rules laid down for riveted joints. Fig. 117 shows the spacing of the rivets of the longitudinal joints as used in one of the large German liners.

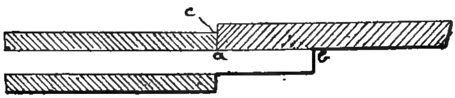


Fig. 118.

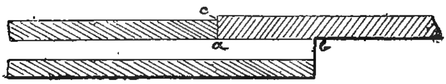


Fig. 119.

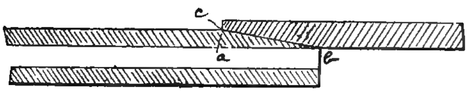


Fig. 120.

The transverse joints, which are subject to lower strains, are usually lap- or scarf-jointed, and have two rows of rivets.

The joint where the longitudinal and transverse seams

cross one another, may be made in different ways. Fig. 118 gives the simplest, but not the strongest, form in general use. The inside longitudinal butt-strap is generally made continuous throughout the total length of the transverse joint, as shown in Fig. 119, thus increasing the length of the longitudinal joints fitted with double butt-straps by the distance *a b*. As the rivets nearest to

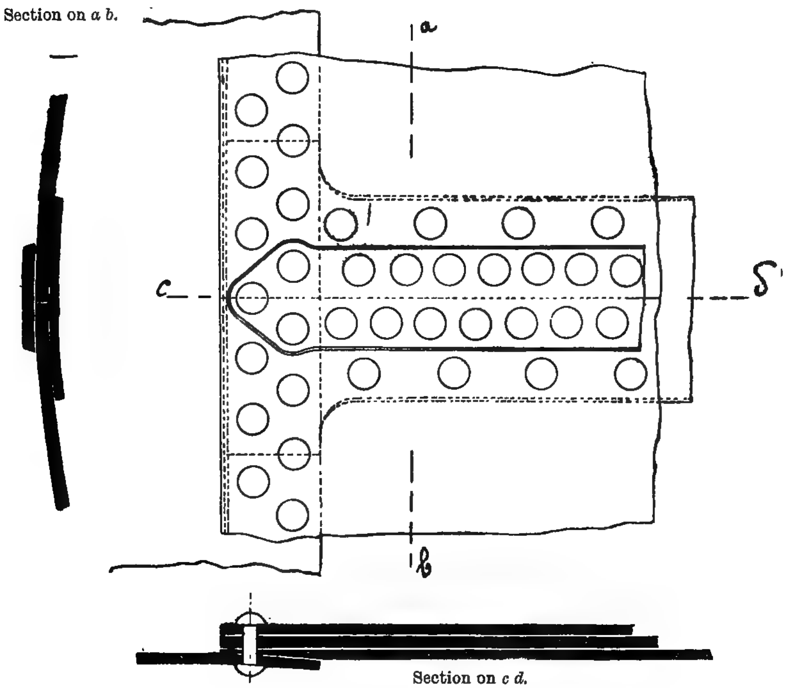


Fig. 120A.

the ends of the butt-strap are liable to particularly excessive strains, and as the caulking at *c* is very difficult to keep tight, the arrangement shown in Fig. 120 may be used with advantage, as the plates have no tendency to slip at the caulked joint *c*.

The ends of the inside butt-straps which come between

the two plates of the shell are splayed out, as shown in Fig. 120A.

On the flat ends of the boiler the joints are double riveted, and are always much stronger than the solid plates themselves, as these latter are weakened by the openings of the tubes and furnaces. Boiler-ends stamped out, as they sometimes have been, of one piece, may be looked upon rather as a feat of manufacture than as fulfilling the conditions dictated by the necessities of construction.

The upper portion, and some parts of the lower portion,

MARCEAU.

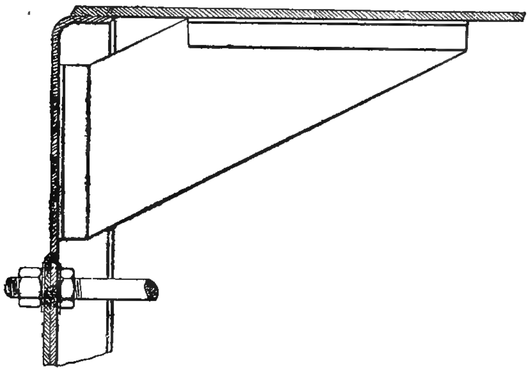


Fig. 121.

(Figs. 70 and 70A), of the boiler-ends, where not stayed, as in the steam-space, are held together by tie-bolts calculated to bear the whole pressure of the steam. These tie-bolts are generally spaced about 16 ins. apart, leaving room for a man to pass. They are fastened to the plates by two nuts, one inside, the other out (Figs. 121, 122). The interior nut is provided with a washer only, a good red-lead joint being made between it and the end-plate. Red lead in this position is not objectionable. The exterior nut, which

takes all the strain, bears on a large, thick plate, often riveted to the shell and strengthening it locally so as to prevent any bulging of the main plate in the vicinity of the bolt.

The boiler-ends are turned over so as to make a joint, with the shell-plates. Fillets are used with as large a radius as possible, in order not only to relieve the strain on the plates, but also to give the joints between the end-plates and the shell a certain amount of elasticity, or rather flexibility, to which considerable importance is attached in high-class boiler-work.

Sometimes the shell- and end-plates are stayed together by gusset-plates and angle-irons so arranged (Fig. 121), as not to fit all the contours of the joint, whereby the work is much simplified. These gusset-plates make the joint very rigid and do away with all the elasticity of the fillet; their usefulness is, therefore, more than doubtful, and, indeed, they are seldom employed at the present time. The edge of the end-plates at the joint with the shell is now, as a rule, turned outwards, as shown in Fig. 122, and hydraulic riveting is thereby much facilitated.

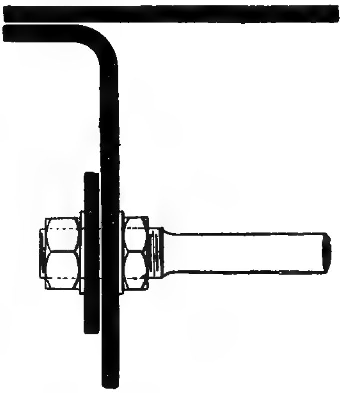


Fig. 122.

The riveting of boiler shells, though following the ordinary accepted rules for riveting, must be done with great care, and almost entirely by hydraulic machinery. Stationary riveters are employed on the cylindrical shell and at its junction with the end-plate. For the front and back portable riveters with deep gaps are used, one arm of which is inserted into the furnace mouths; the furnaces, if arranged as in Fig. 90, are riveted to the ends by hydraulic

riveters. The work of the hydraulic riveter can be regulated to a nicety. The total pressure exerted on the rivet should be about 95 tons to the square inch; if the pressure be too small, the rivet is badly closed, the hole is not completely filled, and the plates are not well brought together; if the pressure be too great, the metal spreads between the two plates and keeps them apart, as shown in Fig. 123. To avoid this defect a concentric die holds the plates together while the rivet is being closed.

The caulking of the shell-plates, indeed the work on every part of the boiler as a whole, requires very great skill on the part of the boiler-makers. The work is a deafening one in the shops, and particularly awkward for the men who have to work inside the boiler itself. Of late, small pneumatic riveters and caulkers, worked by compressed air, have been introduced, which, by a series of blows in quick succession considerably reduce manual labour and the amount of noise.

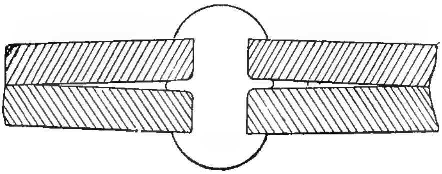


Fig. 123.

97. *Strength of Boiler Shells.—Stress on Materials.—Unequal Expansion.*—It is only in the case of cylindrical shells that reliable calculations of the stress on the material can be made, and by assuming hypothetical conditions the formulæ become very simple. It is usually taken for granted that the back and front do not in any way assist the shell against bursting pressure, and also that any increase of diameter is uniform throughout its length, so that the shell-plates are uniformly stressed throughout. Let

l be the length in inches.

d the diameter in inches, and

t the thickness of the shell-plates in inches; let, also,

P be the pressure in the boiler in lbs. per square inch and,

T the tensile stress on the material, per unit of length, in lbs. per square inch.

The total load on the shell-plate is therefore:

$$l\,d\,P.$$

The resistance is: $2\,l\,t\,T$.

From which it follows that: $2\,t\,T = d\,P$

$$\text{(1)} \qquad T = \frac{d\,P}{2\,t}$$

Though not exact, it may be assumed that the values of T, obtained in this way, are at any rate proportional to the maximum load, and can therefore be compared on different boilers. Equation (1) gives:

—	P Lbs. per Sq. In.	d Ins.	t Ins.	$\frac{d\,P}{2\,t}$ Lbs. per Sq. In.	—
Return-tube boilers.					
Cécile . . .	89	176·4	0·925	8,501	This formula does not take into account the resistance of the overlapping of the plates $\Delta\,l$ which must be added to l; *i.e.*— $T = \frac{d\,P}{2\,t} \times \frac{l}{l \times \Delta l}$. This correction is, however, not generally made.
Isly . . .	135	118·1	1·181	6,754	
Marshall boiler .	160	150·8	1·094	11,026	
Savoie and *Lorraine*	170	205·0	1·26	13,910	
Direct-tube boilers.					
Marceau . .	85	137·8	0·866	6,762	
Davout . . .	160	115·7	0·905	10,227	
Wuttignies . .	160	113·0	0·905	9,989	

Tensile stresses, which are not comparable in different types of boilers, vary in a singular manner in boilers of the same type.

Of late years the values of T have been greatly increased,

and have risen from about 4 to 4.9 tons per square inch, and even as high as 6.2 tons per square inch. From the point of view of strength this increase is justified by the improvement in the nature of the steel employed. The boilers of the *Cécile* and the *Isly* date from a time when the material for shell-plates had only to comply with the following tests :—

Plates from .80 to 1.20 ins. in thickness :—

Tensile strength	25.5 tons
Extension	26.0 per cent.
Quality factor	51.5

The shell-plates of the *Lorraine* had to stand more severe tests :

Tensile strength	from 32 to 35 tons
Extension	20 per cent.
Minimum quality factor	52

With a pressure of 125 lbs. per square inch these plates are not more stressed than the plates of the *Isly* under a pressure of 95 lbs. per square inch.

The tensile strength laid down by the Engineering Standards Committee in the recent specification for Marine Boilers, published by that Committee, is as follows * :—

For shell-plates :

Tensile strength	28 to 32 tons.
Extension	20 per cent.
Quality factor	48

For plates intended for flanging and welding :

Tensile strength	26 to 30 tons.
Extension.	23 per cent.
Quality factor	49

* Abstracted by permission of the Committee from the Standard Specification for Structural Steel for Marine Boilers. Report No. 14, issued by the Engineering Standards Committee, February, 1905.

For stay-angle and tee-bars:

Tensile strength	28 to 32 tons.
Extension	20 per cent.
Quality factor	48

For combustion-chamber stays:

Tensile strength	26 to 30 tons.
Extension	23 per cent.
Quality factor	49

When nickel steel has been introduced on a practical scale, new and important advances may be looked for, and the following figures will be practicable:—

Tensile strength . . .	38 tons per sq. in.
Extension	30 per cent.
Quality factor	68

With a limit of elasticity of 25.5 tons per square inch the steel is no nearer the breaking strength than with ordinary steel with a lower limit.

The figures given for the elasticity of nickel steel vary considerably with different experimenters, due, no doubt, to differences existing in the material itself.

A table of results, by Mr Hadfield, is given on p. 280.

An addition of 5 per cent. of nickel gave a material suitable for plates, having a tensile breaking strength of 38.2 tons per square inch, with a limit of elasticity of 28.6 tons per square inch. An addition of 25 per cent. of nickel, which has been referred to above in connection with the subject of corrosion, cannot as yet be used in practice.

An increase of 20 per cent. in the stress in the plates allows the pressure to be raised from 170 to 220 lbs. per square inch in a boiler of 16.1 feet in diameter, such as the boilers of the *Lorraine*. With boilers of 12.4 feet diameter and three furnaces the same thickness of plates would stand a

TABLE.

Specimen Mark.	Percentage of Nickel.	Unannealed test-bars				Annealed test-bars			
		Elastic Limit	Breaking Load	Elongation in 2 in.	Reduction of Area	Elastic Limit	Breaking Load	Elongation in 2 in.	Reduction of Area
		tons sq. in.	tons sq. in.	per cent.	per cent.	tons sq. in.	tons sq. in.	per cent.	per cent.
A	0·27	19	31	35	56	20	28	37	52
B	0·51	20	30	36	62	21	27	41	63
C	0·95	25	33	31	53	20	27	41	63
D	1·92	26	34	33	55	22	31	56	53
E	3·82	28	37	30	54	25	33	35	55
F	5·81	28	41	27	40	28	37	33	51
G	7·65	31	49	26	42	30	45	26	41
H	9·51	42	85	9	18	32	56	2	2
I	11·39	65	94	12	24	45	89	12	26
J	15·48	55	94	3	2	...	68	1	1
K	19·64	47	91	7	6	45	87	5	4
L	24·51	32	77	13	14	25	78	14	8
M	29·07	25	38	33	44	16	37	48	51
N	49·65		No test	made.		15	36	49	53

See Inst. C.E., Proceedings, vol. cxxxviii., p. 12.

pressure of 280 lbs. per square inch. In some cylindrical boilers, a pressure of 270 lbs. per square inch has already been reached, a similar pressure to that in use with tubulous boilers.

An increase in the tensile stress to which the shell-plates are exposed, though it may not affect the strength or safety of the boiler shell, if accompanied by a proportionate increase in the elastic strength of the steel, may give rise to local and internal straining. This addition to the tensile strains, while not endangering directly the strength of the shell, may give rise to excessive straining of the internal parts of the boiler.

The increase in the diameter, taken as uniform, would, under the premises stated, be represented by the equation:

$$(2) \qquad d \times \frac{T}{E} = \frac{d^2 P}{2\, t\, E},$$

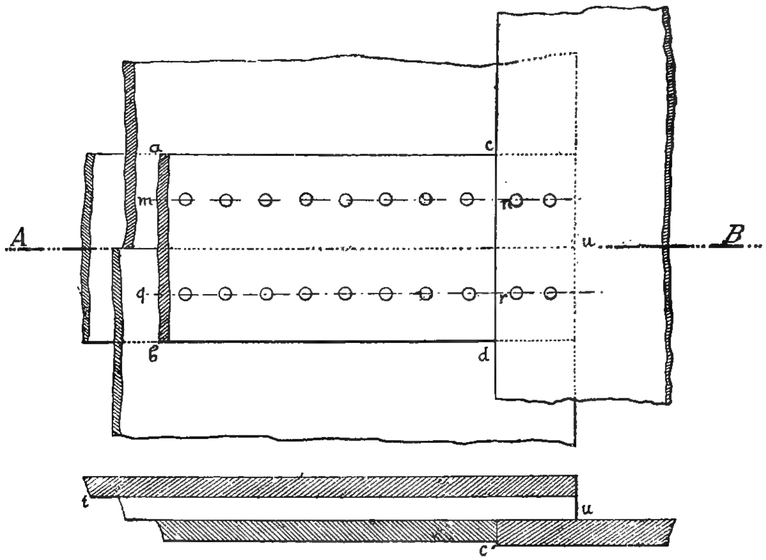
where E is the modulus of elasticity.

Under the hydraulic test, which usually amounts to 2 P when P is below 85 lbs., and to P+85 lbs. when P is above 85 lbs., it is found that, in the centre of the boiler where the measurements are noted, the increase of diameter is greater than is given in equation (2), and may be as much as 0.001 d. Now an increase of $\frac{3}{16}$ths of an inch in a boiler of $\frac{3000}{16}$, or 15 feet $7\frac{1}{2}$ inches diameter, would cause the tube-plate to move considerably in those parts where nearly the whole width of the plate has been cut away, and the crown of the combustion-chamber would be considerably strained where stayed.

If the shell-plates had only to resist a tensile strain in a direction perpendicular to the axis, the expansion per unit length in this direction, $\frac{T}{E}$, would be followed in the direction of the axis by a proportionate contraction $\frac{T}{E} \times \frac{1}{\mu}$. The co-

efficient μ is generally taken as equal to 3. When, therefore, $\frac{T}{E}$ amounts to 0.001, the contraction $\frac{T}{E} \times \frac{1}{3}$ is quite an appreciable quantity, and would be represented by $\frac{3}{32}$nds of an inch in a direct-tube or Admiralty boiler $\frac{9000}{32}$, or 25 feet $5\frac{1}{4}$ inches, long.

No general diminution in the length of the boiler has, to the knowledge of the Author, been noted. Indeed the



Section on A B.

Fig. 124.

shell undergoes a longitudinal tensile strain caused by the end-plates, which tends to neutralise any shortening action. But there are partial contractions which explain, in a sufficiently plausible manner, certain local strains which show themselves, for instance, by very slight leaks at the ends of the longitudinal butt-straps. Take the longitudinal butt-strap, *a*, *b*, *c*, *d* (Fig. 124), which butts at *c*, *d*, on the adjoining ring of the shell; suppose it to have a single row of

rivets on either side of the joint t, u (for this will not affect the argument), m, n, and q, r, are lines through the centres of these rivets. The part m, n, q, r, of the butt-strap is affected by the extension $\frac{T}{E}$, and, consequently, by the general contraction of the butt-strap lengthways proportional to the coefficient μ. But, as the two parts a, c, m, n, and b, d, q, r, which are unstrained, do not alter in length, they have a tendency to force the adjoining ring at c, n, and r, d, and thereby to cause a leak at n and r. Other parts of the boiler might be selected where a pulling effect is observed; but the above is the best established proof of those partial actions to which reference has been made.

The end-plates tend to produce a strain on the shell in accordance with the formula $\frac{1}{4}\ \pi\ d^2\ P$.

In a boiler without stays the whole of the pressure would be transmitted to the shell, which would, therefore, bear a tensile strain T_1 determined by the equation:

$$\text{(3)} \qquad \pi\ d\ t\ T_1 = \tfrac{1}{4}\ \pi\ d^2\ P.$$

$$\text{(4)} \qquad T_1 = \tfrac{1}{4}\frac{d}{t}P = \tfrac{1}{2}\ T.$$

Instead of contracting, the shell would, therefore, expand in the direction of its axis by an amount equal to:

$$\text{(5)} \qquad \frac{T}{E}\left(\frac{1}{2} - \frac{1}{\mu}\right) = \frac{T}{E} \times \frac{1}{6}.$$

In actual practice the stays take almost all the end thrust, and the shell only bears one-sixth of it at most; it is, therefore, only the stays that lengthen.

The exact analysis of the strains in the cylindrical shell is difficult enough, but those of the two end-plates baffle all solution. It has been assumed that the two ends do not affect the tranverse strength of the boilers; there is an evident want of agreement between this hypothesis and the one which assumes that the cylindrical shell expands uniformly.

Unless the rounded-over portions of the end-plate give, the uniform expansion of the diameter of the shell, along the whole length of the boiler, would bring on to the end-plates (even supposing them whole and not cut out at all) strains per square inch considerably higher than those in the shell. Under the hypothesis assumed, both the ends and the shell-plates expand in the proportion $\frac{T}{E}$; but they expand in all directions, instead of expanding in one direction and contracting in the other, by the quantity $\frac{T}{E} \times \frac{1}{\mu}$.

Under these conditions the total load on the end-plates T_1 is given by the equation:

$$(6) \qquad T_1 = T \frac{\mu}{\mu - 1} = \frac{d\,P}{2\,t} \frac{\mu}{\mu - 1};$$

taking $\mu = 3$:

$$(7) \qquad T_1 = \frac{3}{2} T.$$

Owing to the cutting away necessary for the tubes and furnaces, the end-plates would be quite incapable of resisting such a tensile strain. Now, neither at the back nor in the front do any of the plates, or even the rivet-joints, ever show any signs of distress, even in boilers where the gusset stays described above prevent any movement at the joint between the ends and the shell. The natural conclusion to be drawn from this is, that the ends are only very slightly expanded. It is not difficult to see why this is so. In reality the expansion of the boiler, in the direction of the diameter, is anything but uniform; it may amount to 0.001d in the centre part, but it is very much less at the end; the shell, in changing shape, takes the form as shown in Figs. 125 and 126. The cause of this difference in the expansion (in the direction of the diameter) lies in the resistance of the ends; it may also, probably, be due to the deformation to which the ends

are subject under the action of pressures parallel to the axis. The end-plates, indeed, have a tendency to sag round the stays, and this should lessen their diameter. It is not beyond the range of possibility that the shells, near their extremities, are subject to slight reductions of diameter, instead of to an increase; this is shown in Figs. 125 and 126, in which the line *m*, *n*, represents the original shape of the boiler before the deformation takes place. In this latter case the total tensile strain on the shell, expressed by the equation:

$$2\ t\ \Sigma\ \mathrm{T}\ dl = l\ d\ \mathrm{P},$$

would be the resultant of variable tensile strains T, of which the greatest value would be very much larger than $\frac{d\,\mathrm{P}}{2\,t}$.

The preceding considerations show the advantage of allowing some change of shape at the joints between the shell and the end-plates, so as not to force the former to bend, in the manner indicated in Fig. 125, by sagging.

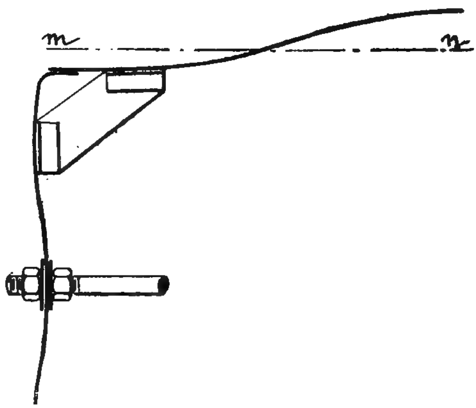


Fig. 125.

There is nothing to be learnt, even for the sake of mere comparison between one boiler and another, by investigating the stress on the metal, T, on the supposition that the ends and the shell expand as a rigid whole, nor in using the equation

(8) $$(2\ lt + 2\ dt_1) = l\ d\ \mathrm{P},$$

as has sometimes been done. The facts do not warrant it.

Pressure is not the only cause of strains in the shell;

difference of temperature between the top and bottom is another. The hotter water naturally rises, leaving the remainder comparatively cold, collected at the bottom, where it is further cooled by the ashpits, through which a strong current of cold air is constantly passing. The top, therefore, expands much more than the bottom, unless there is in the boiler a circulation brisk enough thoroughly to mix up the whole mass of water.

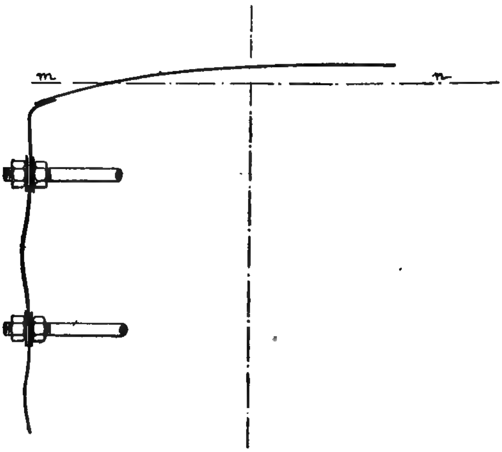


Fig. 126.

Let m, a, b, n (Fig. 127) represent the half of a boiler on the right of the section m, n, before lighting up. The

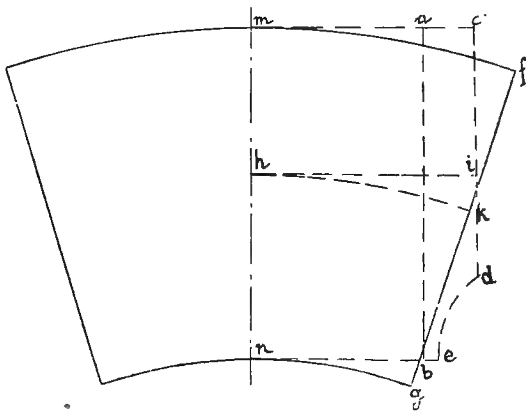


Fig. 127.

different elongations due to the temperatures at each point, if they were free to act, would give to each layer

such a length that the section would become similar to *m*, *c*, *d*, *e*, *n*, but this is obviously impossible. Hot or cold the boiler must end in a plane normal to its own axis; it therefore often takes a form similar to *m*, *f*, *g*, *n*. It will be seen at once that, by this change of shape, while the central strip *h*, *i*, maintains its length, as at *h*, *k*, the outer layer *m*, *f*, becomes longer than *m*, *c*; while the innermost layer *n*, *g*, becomes shorter than *n*, *e*. The upper fibres are, therefore, in tension, and the lower ones are in compression. On the *Surcouf*, where the difference of temperature reached 216° Fahr., it was calculated that the compression of the innermost fibres corresponded to a load of 12.7 tons to the square inch on the outside butt-straps, over and above any other strains. This shows how necessary it is thoroughly to agitate and circulate the water in order to avoid these great differences of temperature, more especially in direct-tube boilers like those on the *Surcouf*.

98.—*Permanent Set and Deformation.*—While investigating the strains to which different parts of the furnace, combustion-chamber, and shell, are exposed, whether by reason of unequal heating and expansion, or of steam-pressure, it is always taken for granted that the parts are not initially strained, and are in the same condition as when under erection; in other words, it has been assumed that the elastic limit of the metal has never been exceeded, nor its physical properties in any way altered by former heatings. This is anything but the case in actual practice.

When a strip of metal, free to change its shape, is unequally heated, permanent set is produced. To take the most simple case: suppose, for instance (Fig. 128), that a strip of plate *a b c d* is highly heated on its lower portion *e f c d*, while *a b e f* remains cold; the expansion which should lengthen *d f* to d^1 f^1 being neutralised by

the resistance of the cold part, the lower heated portion is compressed beyond the limit of elasticity; at the same time the upper cold portion is stretched beyond the same limit, and, in addition, is not in any way annealed. On cooling, *a b* will be longer than *c d*, and the piece of plate will take the shape a_1 b_1 c_1 d_1. Skilful boiler-makers are well aware of the effects of partial heating, and make use of them sometimes to obtain, without any hammering, pieces of plate of complicated shapes.

These phenomena have been investigated by Mr Yarrow, and M. Garnier, of the French Navy, has

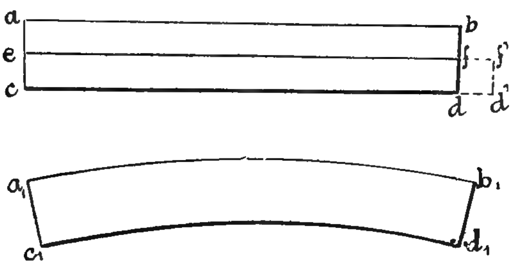


Fig. 128.

followed up the subject more thoroughly at Indret by experimenting on strips of iron and steel, with their ends butted against strong and rigid castings. M. Garnier made further experiments more nearly approaching the conditions met with in practice, where the strips are firmly secured at either end, and are stayed in the centre like fire-boxes (Fig. 129). Finally, he experimented on discs of iron, steel, and brass plate, exposed to local heating. The results obtained agree very closely with those given by theory; they have confirmed the occurrence of permanent sets in plates free to expand, and also the phenomena known as "blistering."

The greater number of the different parts of a boiler are so put together that they cannot alter in shape; it

follows that, instead of permanent set, permanent molecular tension must be set up. These tensile strains are clearly, manifested when a boiler is broken up. It often happens when knocking off the heads of a row of rivets, that the last ones strip off themselves, or, at any rate, that, on taking out the rivets, the plates suddenly slide over one another, so that the holes are no longer fair. It is probable that these interior tensile strains have something to do with the accidents to which boilers are liable.

And, further, experience would appear to show that both iron and steel deteriorate, change their molecular

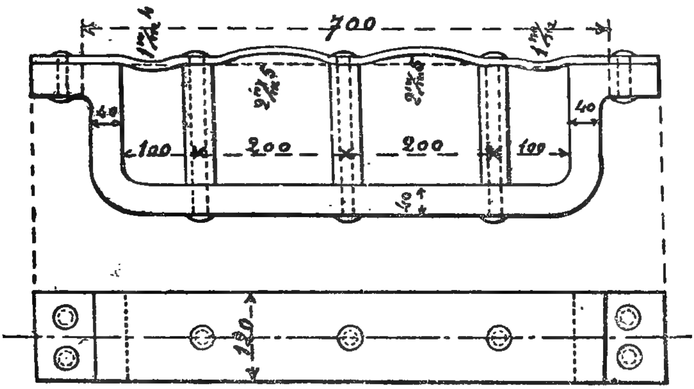


Fig. 129.

texture, and become very brittle by being repeatedly heated and cooled. This would account for the somewhat frequent giving out of the seam between the furnace and the combustion-chamber, a point where strains due to pressure are moderate, but where the local heating is excessive. This is one of the numerous deteriorations of the metal known to boiler-makers as "burning." It is also to be noted that those parts most exposed to great variations of temperature are, at the same time, subject to unequal distribution of temperature, causing internal compressive and tensile strains beyond the limit of elasticity,

CHAPTER IX

LOCOMOTIVE BOILERS

§ 3. APPLICATION OF LOCOMOTIVE BOILERS TO THE NAVY.

99. *Reasons for the Adoption of Locomotive Boilers.*—The preceding chapters have been principally occupied with the cylindrical boiler, which is the type till recently most largely used upon warships, and is also, with very few exceptions in general use in the mercantile marine. There is, however, another form of tubular boiler, which differs materially from the ordinary cylindrical type; it is known as the *locomotive boiler.*

Two reasons have led to its introduction into the navy, namely:—

(1) *The question of weight.*—Cylindrical boilers are very heavy on account of the large volume of dead water in the lower part of the boiler, especially in boilers of the non-return or direct-tube type. In locomotive boilers, on the contrary, the furnace is only surrounded with small water-spaces, which are just sufficient to utilise the heat. For a working pressure of 130 lbs., at which locomotive boilers were first worked, their weight was about $\frac{8}{11}$ths of the weight of a direct-tube cylindrical boiler working at the same pressure.

(2) *Ability to stand high rates of forcing.*—Forced draught has from the very beginning been employed upon loco-

TORPEDO-BOAT NO. 60.

LOCOMOTIVE BOILER (TYPE E).

Section on C D

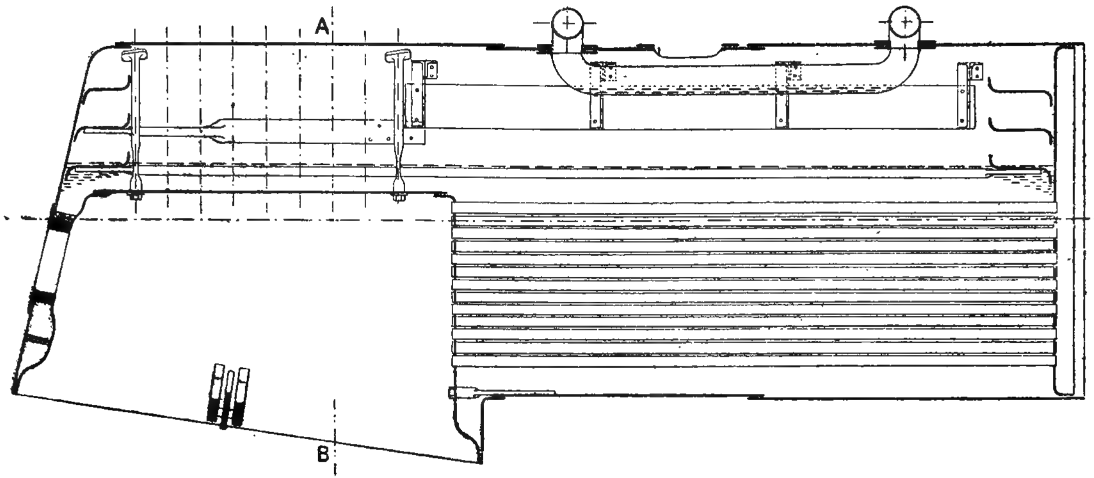


Fig. 130A.

Section on A B

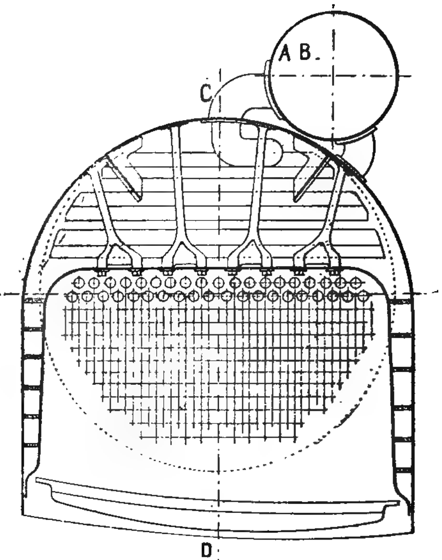


Fig. 130.

motives; it was therefore natural that when forced draught was introduced into the navy, the boilers which had always been associated with forced draught should be introduced at the same time.

The preceding considerations lead to the anticipation that locomotive boilers would come into general use in the navy, but these expectations have not been realised and their employment has been limited to certain classes of vessels. They have only been in use on torpedo-boats, and torpedo-gunboats, and have now given place to the tubulous boilers, and these are now entering into competition with the cylindrical boiler upon larger vessels.

In England, locomotive boilers were adopted for the coast-defence vessel *Polyphemus* in 1879, but they proved so unsatisfactory that they were removed after a few trials and direct-tube boilers substituted. Locomotive boilers were also fitted in some torpedo-gunboats, and in one or two of the earlier torpedo-boats and torpedo-boat destroyers, but they have now nearly all been replaced by tubulous boilers. In Italy, sixteen boilers of this type were fitted a few years ago on the *Lepanto*, and they are probably still in service. The most extensive use of this class of boiler was in the German Navy, on the cruisers *Hela*, *Wacht*, *Jagd*, *Komet*, *Meteor*, and on the eight coast-defence vessels of the *Siegfried* and *Beowulf* class; but the substitution of water-tube boilers for locomotive boilers has now been decided upon at least for coast-defence vessels and the *Aegir* has already been fitted with Thornycroft-Schulz boilers.

100. *Description and Construction.*—As the employment of locomotive boilers has not been general, and their complete disappearance is probably only a question of time, a brief description will be sufficient, the reader being referred to works dealing with railway locomotive boilers for the details of their construction. They are distinguished by the

arrangement of the furnace, the two sides and crown of which are flat unbroken surfaces; moreover, the bottom of the fire-box is entirely open to the air, the draught being due to the velocity of the train, as well as to the nozzle. The furnace-plates, including the tube-plate, are now of steel; the tube-plate was formerly made of red copper hardened by hand hammering, which reduced the thickness of the plate by about $\frac{1}{16}$ inch.

The fire-box being high and unobstructed acts as a combustion-chamber.

The outer shell of the boiler in the neighbourhood of the furnace is composed of flat plates stayed to those of the furnace, and the top of the boiler is semicircular in shape, the furnace crown being suspended from it by stays. The rest of the boiler is circular, being in continuation of the semicircular portion above the furnace.

The tubes are very long and of small diameter.

The marine type of locomotive boiler differs principally from the railway locomotive boiler in two points:—

(1) The small amount of head-room available necessitates the grate being placed much higher than in locomotives, and consequently nearer the entrance to the tubes, and the necessary space for thoroughly mixing the gases is consequently very much reduced.

(2) The small amount of room available in length necessitates the employment of shorter and stiffer tubes.

Unless locomotive boilers are handled with considerable care, trouble is sure to ensue; leaky tube-joints occur at draughts much inferior to those in vogue in ordinary locomotive practice. Faults in the furnace-plates, furnace-joints, and tube-plates, and corrosion in the bottoms of the flat water-spaces necessitate frequent repairs. The boilers do not last long, five years (torpedo-boat No. 16 and many others) being the usual life of this type of boiler. The boiler of torpedo-boat No 21, however, lasted

"CHISIMA," JAPANESE TORPEDO-GUNBOAT.

LOCOMOTIVE BOILER WITH "TENBRINCK" FIRE-BRIDGE.

Section on A B.

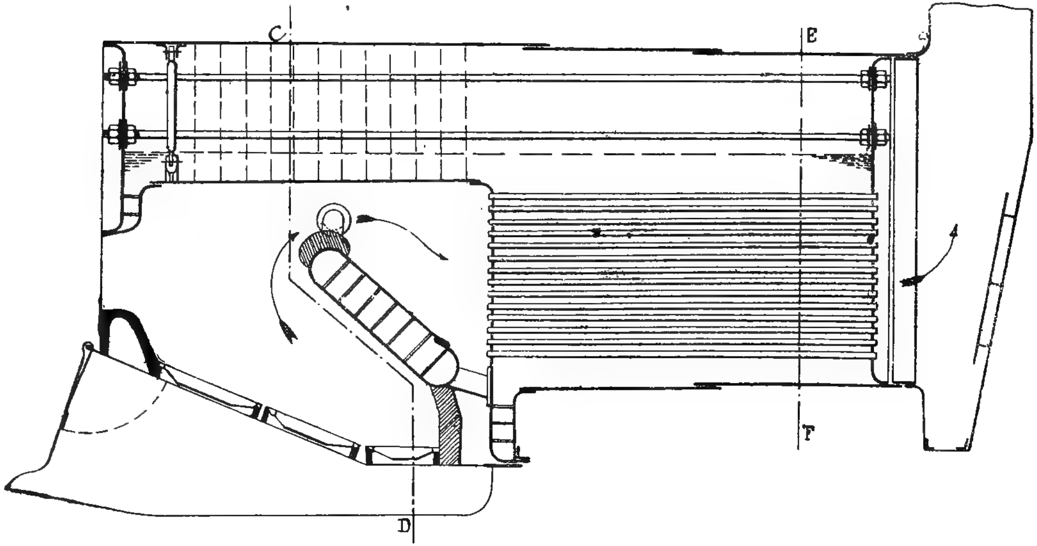


Fig. 131A.

Half section on C D. Half section on E F.

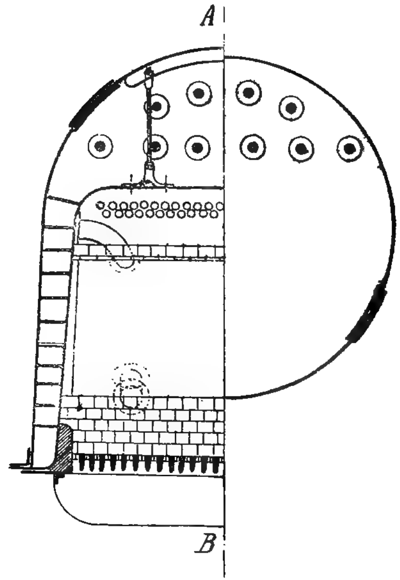


Fig. 131.

for nine years, and that of torpedo-boat No. 37 for twelve, having, during that time, been 5000 hours under steam.

Their numerous failures have been ascribed to many causes. Mr Marshall, for example, attributes them to the lack of circulation near the tube-plate, and proposes fitting a flat water-space under the furnace, where the water, in all probability, would remain stagnant. This arrangement, known as a "wet-bottom" fire-box, was fitted in the British torpedo-gunboats of the "sharp-shooter" class.

Figs. 131A and 132A show two arrangements adopted to prevent the hot gases reaching the tubes too quickly; in the first case, the baffle is formed by a water-space, called a "Tenbrinck" after the inventor, and in the second by a prolongation of the fire-bridge.

Setting aside any defects in design, and above all of position of the grate, the main difference between the life of a boiler on board ship and upon a locomotive depends entirely upon the difference in the nature of the service they are called upon to perform. In locomotives, the boilers are only in use for five or six consecutive hours, after which they are inspected and cleaned; they experience neither change of stokers nor drawing fires, nor cleaning tubes while under steam, or briefly, any of the severe handling which is detrimental even to the strongest and best constructed tubular boiler.

The reason that leaky tube-plates are not so prevalent on locomotives as on board ship is principally because the air-pressure in the furnace is nearly the same as that of the surrounding air.

The pressure in the ashpan, due to the speed of the train, overcomes, in fact, the resistance through the grate; and the draught due to the nozzle has only the resistance of the tubes to overcome. In consequence, the opening of the fire-doors on the locomotive does not give rise to

TORPEDO-GUNBOAT, FAUCON TYPE.

MODIFIED FORM OF LOCOMOTIVE BOILER.

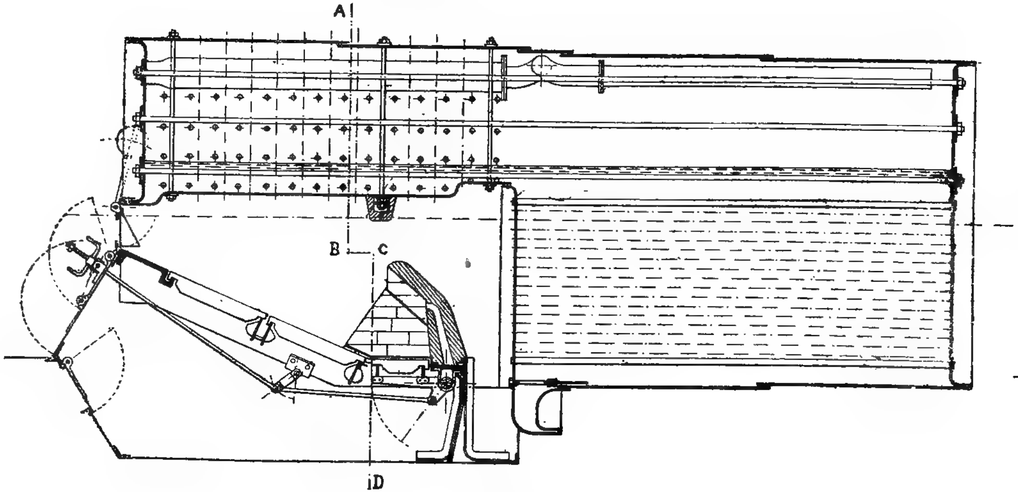


Fig. 132A.

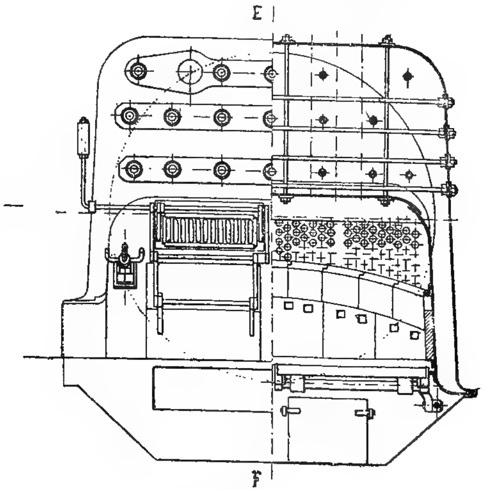


Fig. 132.

the sudden inrushes of cold air, which are so detrimental to the tube-plates of marine locomotive boilers. The resistance of the grate and tubes in these latter has to be overcome by the difference in pressure between the stokehold and funnel. Consequently, the pressure in the furnace being below that in the stokehold, due to the resistance of the

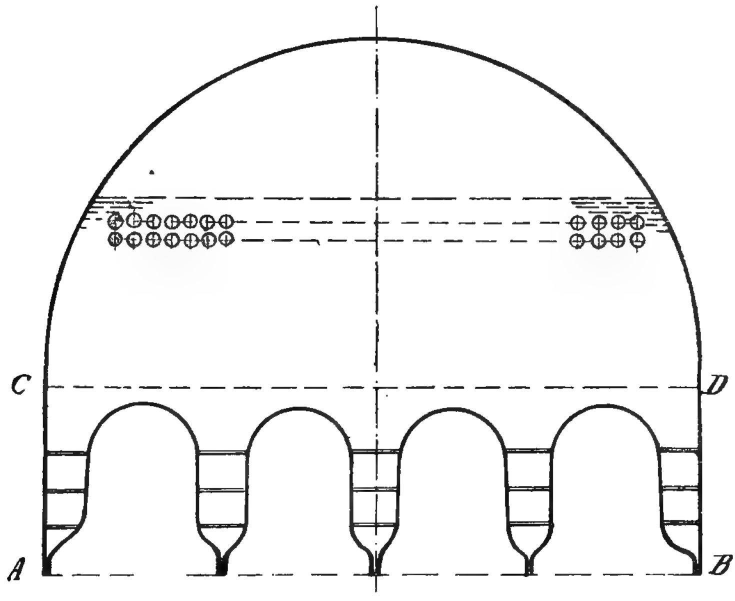


Fig. 133.

grate, any opening of the fire-door must necessarily give rise to sudden inrushes of cold air.

It may also be noted that the flat furnace crowns of the locomotive boiler expose a very much larger surface that is liable to be overheated than do the crowns of cylindrical boilers, should for any reason the feed be stopped. The result of this overheating of the plates is frequently the drawing of the stays, and consequent serious accidents to the stokers. It may be remarked that the economy in

weight realised by the use of direct-tube boilers with a locomotive fire-box, might have been obtained by the use of return-tube boilers, by constructing them as a half cylinder, terminated at the bottom by a row of stayed furnaces. Rigidity could easily have been assured by means of stays placed in the lower portion, either at CD, or even AB, Fig. 133.

This arrangement, which would not have exposed the furnace crowns to any danger, was advocated by M. Joessel at the time when pressures were 56 lbs. per square inch, but it has never been carried out.

CHAPTER X

§ 4. GENERAL REMARKS

101. *Life of Marine Boilers.*—After the foregoing description of the various causes of failure in boilers and the precautions which must be taken to prevent them, it must be admitted that the marine type of boiler, if well constructed and handled with care, is both reliable and durable. Failure is more generally due to the result of chemical action, to which, however, all boilers are exposed, than to any mechanical strains. The most frequent sources of accidents are leaky tube-joints or seams, which give rise to corrosion. The boiler-shell sometimes shows rapid wear round the feed-water inlet, and especially at the water-level. Formerly, the iron furnace-plates were liable to blistering and other defects, which have now been overcome by the use of steel.

Local and deep pitting is often met with at those points where the steam is produced in greatest abundance. It seems as if the steam-bubbles hollow out a sort of nest or forming place at this point; this kind of corrosion is, however, mainly due to the action of air-bubbles. If the air-bubbles once commence to free themselves at any point, they continue to do so until the metal is deeply pitted. This class of corrosion is very rapid, and apparently brings about the liberation of hydrogen, and is further assisted by the presence of carbonic acids. It is chiefly to be feared in non-homogeneous material, or where brazing or welding has occurred. It appears very little, if at all, upon steel,

especially if the metal contains chromium or nickel, and it is entirely prevented by the presence in the water of borax or of an alkali. When they have never been subjected to overheating, the furnace-plates will last as long as the shell-plates.

Iron and steel tubes often corrode at the welds, but brass tubes will outlast the rest of the boiler.

The reduction in thickness of the boiler-plate, brought about by constant wear, is extremely slow. In many liners the boilers are in excellent condition after ten years' service, without having undergone any extensive repairs. Even after they have been removed from the liners, which is generally done after about twelve years' service as a precautionary measure, the same boilers have been worked on cargo boats for another five or six years.

Instances are not wanting where boilers have been in use for over twenty years. As examples may be mentioned, the boilers of the *Notre-Dame-du-Salut* on the Madagascar station; and also those of one of the White Star Company's liners, which were put in in 1871, and were still in good condition in 1895.

In the navy, the intermittent nature of the service, the long periods of inaction during which the vessels must be held in readiness to be put in commission at any moment, and the constant changes in the engine-room staff, are not conducive to the long life of a boiler. Under these conditions a boiler is not expected to last longer than eight or ten years, and will have to be thoroughly overhauled at least once during that time. There is, however, the satisfaction of knowing, that, in going into commission with the ship's boilers in good condition, they will last throughout the time the vessel is on a foreign station, and, should occasion arise, the length of time in commission may be doubled without necessitating extensive repairs to the boilers while abroad.

It should be noted that the above refers to return-tube boilers alone, as boilers with straight tubes do not last as long, and locomotive boilers cannot be used for three years without repairs, their life being not more than six years at the most.

102. *Weight of Tubular Boilers.*—In getting out the total weight of a ship, under the head of weight of boilers is included everything that is concerned in their working, in the purification of feed-water, in the production of forced draught, and in general, everything connected with the stokehold, including tools and spare gear. In the nomenclature of the different parts composing this total, a complete list without any omission has been aimed at, which is all that is necessary.

In a work which attempts a comparison of different types, and endeavours to show what changes of weight correspond to a change of system, a more rational method of classification must be employed. The following is most convenient:—

I. *Elements varying with the working pressure* II, and whose weight per square foot of grate ought to be proportional to that pressure.

1. Body of the boiler without fire-bars or masonry.
2. Stop-, safety-, and reducing-valves, separators on steam-pipe and super-heaters.
3. Piping, and cocks and valves in the stokehold.

II. *Elements depending on the rate of working*, that is to say, on the quantity of coal burnt per square foot of grate, and on the quantity of water evaporated per square foot of grate. The total of these weights per square foot of grate should be proportional to the combustion K.

4. Feed-pumps.
5. Feed-water tanks and reserve tanks.
6. Feed-water heaters.

7. Filters and purifying apparatus, and lime water-tanks.

8. Distillers for "make-up" feed-water.

9. Water in feed and reserve tanks, and in the above-named fittings.

10. Fans for forced or suction draught.

III. *Elements independent of both* II *and* K which ought to be directly proportional to the grate-area G.

11. Water in boilers.

12. Grates, fire-bricks, and fire-bridges.

13. Funnels, uptakes, and smoke-boxes.

14. Non-conducting coverings, casings, and lagging of all kinds.

15. Tools and spare gear.

16. Stokehold floors and ladders.

Logically, these latter should be classed with the hull.

It is very seldom in the machinery lists that any means are found of allotting correctly the total weight among these three groups—P_1 the weight varying with the pressure II, P_2 the weight varying with K, and P_3 the weight independent or nearly so of II and K. Most frequently, only the total weight, $P = P_1 + P_2 + P_3$, is given, the subdivisions being merely arbitrary distinctions for the purpose of simplifying the classification.

Whatever the type of a boiler may be it is characterised as far as weight is concerned by the ratio

$$(1) \qquad \frac{P}{G} = A$$

the weight per square foot of grate. It is necessary, in order to ascertain its true value, to determine its relation to the water evaporated per square foot of grate, but as this is hardly ever known, it is replaced by the power developed per square foot of grate.

$$(2) \qquad \frac{F}{G} = B$$

where F is the total indicated horse-power,

The power B per square foot of grate is a very complex element; it depends upon the combustion K and upon two quantities, the water evaporated per pound of coal, and the horse-power of the engine per pound of steam. Going back to the only data usually given, which refers to these two quantities, namely, the coal per horse-power hour C, we have

$$(3) \qquad C = \frac{K}{B}$$

From the value of D the weight of a boiler per horse-power, we have

$$(4) \qquad D = \frac{P}{F} = \frac{P}{G} \times \frac{G}{F} = \frac{A}{B} = \frac{AC}{K}$$

This weight is then proportional to the weight per square foot of grate and the consumption of coal per horse-power, and inversely proportional to the weight of coal burnt per square foot of grate.

It is known that the consumption per horse-power C diminishes rapidly as the pressure rises; this is due to the efficiency of the engine, which improves with the greater number of expansions possible with high pressures, but not to the direct effect of the pressure, as may be readily shown in the following manner.

The boiler can evaporate practically the same amount of water at all pressures, especially when the pressures are high; this may be seen by reference to the Table in paragraph 23, giving the total quantity of heat Q contained in one pound of steam at varying pressures.

On the other hand, the volume of one pound of steam V is nearly inversely proportional to the pressure II at the high pressures now in use; its value in cubic feet may be roughly calculated from the equation

$$\Pi V = 440.$$

The two quantities, Q and II V, both remaining practically constant, neither the efficiency of the boiler nor that of the

engine would change if H varied; consequently, C would remain constant if the rate of expansion was not altered.

When the rate of expansion varies, only the weight per horse-power of boilers supplying steam to similar engines can be compared. The weight A per square foot of grate expresses the lightness of a boiler for a similar consumption of coal K; their weight per horse-power D expresses their fitness to support this consumption K. The following ratio then exists between these two weights:—

$$\frac{A}{D} = \frac{K}{C}$$

in which C is assumed constant.

In grouping together similar boilers and classifying these groups according to the number of successive expansions in the engines, the following Tables are formed for the most recent types of tubular boilers:—

In Table I. the total weight P is generally taken from the table of weights, allotting to the boilers 40 per cent. of the total weight of tools and spare gear allowed for boilers and engines; the error committed in certain cases by this has no appreciable influence upon the values of A and D.

The power F is the maximum horse-power obtained with forced draught and with a consumption of coal K. As in many cases, similar boilers, or at least, boilers which are capable of standing the same intensity of draught, have been experimented upon at very different draughts, depending upon the consumption of steam of the engines, the figures in column A give a better means of comparison of different types than do those in column D.

Table II. gives the weight of the several component parts of a boiler classified as elements depending upon the pressure, elements depending upon the consumption of coal, and elements depending directly upon the grate-area.

103. *Space Occupied.*—Having given the weights of the

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various types of tubular boilers, the following Table gives the space occupied :—

TABLE III.

		Name of Ship.	Horizontal projection in Square Feet— of the Boiler c.	Horizontal projection in Square Feet— of the Grate g.	Ratio $\frac{c}{g}$
Single-ended boilers.	2 furnaces . . .	*Sfax*	102·39 110·85	42·95 46·75	2·384 2·371
	2 ,, . . .	*Manche* . . .	92·17	43·81	2·104
	3 ,, . . .	*Amiral-Baudin* .	106·3	63·61	1·671
	3 ,, . . .	*Isly*	150·16 144·63	73·74 70·29	2·036 2·058
	3 ,, . .	SS. *Bretagne* (old boilers) . . .	145·12	70·07	2·071
Double-ended boilers.	3 furnaces (combustion chamber common to all three) .	*Cécile* . . .	252·75 250·0	142·09	1·779 1·759
	3 furnaces . . .	*Capitaine Prat* .	266·57	137·76	1·935
	4 furnaces (2 combustion chambers separated by a water-space) . .	*D'Entrecasteaux* .	280·10	194·28	1·441
	4 furnaces (2 combustion chambers separated by a water-space) . .	*Columbia* . . .	329·33	168·01	1·960
Admiralty boilers.	3 furnaces . .	*Hoche* . . .	216·62	70·00	3·094
	3 ,, . .	*Matsou-Sima* . .	183·91	64·59	2·848
	2 ,, . . .	*Dupuy de Lôme* .	201·48	57·15	3·525
	2 ,, .	*Suchet* . . .	189·61	46·93	4·040
	2 and 3 furnaces. .	*Linois*	185·06 161·52	71·20 51·99	2·599 3·107
Locomotive boilers.	1 furnace. . . .	Torpedo-boats, Nos. 105 to 114	94·81	24·76	3·830
	1 ,, ...	Torpedo-boats, Nos. 126 to 129	116·03	30·35	3·823
	1 ,, ...	*Bombe*	77·79	19·37	4·016
	1 ,, ...	*Achéron* . . .	95·06	19·16	4·961

PART III.

TUBULOUS BOILERS.

GENERAL CONSIDERATIONS.

104. *The Introduction of Tubulous Boilers into the French Navy.*—The construction of marine boilers, at least those for use in warships, has undergone complete transformation. The old style of boiler, with the fires and hot gases surrounded by the water and steam which in the bygone days of wooden hulls afforded valuable protection against accidental fires, has been abandoned. In the types now in use the water is surrounded by the hot gases.

The material of which the boiler tubes are composed is no longer in compression, as was the case in the older type of boiler, the principal stresses in the new type being of a tensile character.

The boiler casing is usually of thin plate, often protected on the inside by water-tubes arranged in the form of a tube wall, and the casing plates are always covered by a non-conducting material. It is therefore the casing and not the boiler-shell which forms the outside of the boiler.

In the early days the form of the boiler had such an influence on the pressure and method of construction that it determined the names by which the different types of boilers were known, such as "Rectangular" and "Cylindrical," but to-day the shape is no longer of importance as a basis of classification.

Although the difference between the two systems, one of which has gradually replaced the other, is clearly marked, a universally accepted name accurately describing them has not yet been arrived at. The name, "Water-Tube Boiler," as opposed to "Fire-Tube Boiler," is not satisfactory, because there have been rectangular boilers with water-tubes (Martin or Cochrane Boiler).

In reality, one of the principal differences in the two types lies in the casing or shell, but it should be noted that there are several types of water-tube boilers having walls composed of flat plates with a water-space between them. The name "Multi-tubular Boiler" is quite unsuitable for a type which sometimes contains fewer tubes than the older type, and merely serves to convey that the boilers are *very tubular*, all the heating surface being composed of tubes.

In contradistinction to "Tubular Boiler," the name which custom has allotted to the old cylindrical or rectangular boilers, the term "Tubulous Boiler" will generally be used, as it has at least the merit of simplicity. The name, however, is of little importance, as in reality there is little risk of confusion.

It is hardly accurate to apply the adjective "old" to tubular boilers, and "new" to tubulous boilers, as several types of tubulous boilers existed before cylindrical boilers; but whilst twenty or thirty years ago tubular boilers, on taking a cylindrical form, came into general use, the development of tubulous boilers has, on the contrary, been very slow. The increasing importance of weight, and the adoption of pressures too high for other boilers, necessitated the introduction of tubulous boilers.

In spite of their acknowledged advantages, two causes helped to retard the adoption of tubulous boilers. The first was the difficulties experienced in working, which were only surmounted by degrees, and which even at this

present moment have not been entirely overcome; the second was the corrosion of the thin tubes, which always renders the durability uncertain. In this respect progress has also been made; and it should not be forgotten that the adoption of steel tubes in cylindrical boilers has diminished the early superiority of this class of boiler. The two great objections to the tubulous boiler have, therefore, gradually lost their weight. At present, in most navies, tubulous boilers are exclusively used on torpedo-boats, and on the class of enlarged torpedo-boats now becoming more and more numerous, such as destroyers, and torpedo-gunboats. They are being extensively used on cruisers, and are beginning to be adopted on ironclads. Cylindrical boilers are still employed on a few warships intended for foreign service. Tubulous boilers are rarely met with in the merchant service. The recent extensive adoption of these boilers in the navy is principally due to the early experience acquired on torpedo-boats.

The different types of tubulous boilers are of extremely varied construction. Some types have only been employed on land, but those only will be considered which have been adopted on board ship, dismissing in a few words all such as have not yet found their way into general use afloat. Leaving aside constructive details, the boilers are most readily classified according to the means adopted for securing the circulation of the water. Thus, in Chapter II., three different groups were mentioned, boilers with *limited circulation*, those with *free circulation*, and those having *accelerated circulation*. This classification corresponds fairly well with the order in which the boilers were invented.

Boilers with *limited circulation*, which might also be called coil boilers, are characterised by the absence of water-reservoirs. The Belleville is typical of this group.

Boilers with *free circulation* might also be called boilers

with vertical reservoirs and horizontal tubes, the reservoirs being generally formed of two rectangular or flat water-spaces. The principal and best known inventors in this group for the French types, are Joessel, D'Allest, Collet, and Niclausse, and Babcock & Wilcox for the American.

Boilers with *accelerated circulation* have, as a distinguishing characteristic, vertical tubes of various shapes connecting horizontal and generally cylindrical reservoirs. The earliest inventors were M. Sochet and Commander Du Temple. The boilers of this group, constructed by Thornycroft, Normand, Yarrow, Mosher, Guyot, and several others, of which particulars will be found further on, vary very considerably in form.

The three terms *limited*, *free*, and *accelerated*, do not indicate successive and regularly increasing degrees or rates of circulation. *Free circulation* is, in fact, free to be insufficient or perfect, as the case may be.

For instance, it is possible that steam may be more liable to accumulate in certain tubes of a D'Allest, Babcock and Wilcox or Niclausse boiler than in those of a Belleville boiler, though the first belongs to the class with *free* and the latter to that having *limited circulation.*

Even in a boiler of *accelerated circulation*, there might be a few tubes in which the circulation is feeble, though it could never be entirely absent.

CHAPTER XI.

BOILERS WITH LIMITED CIRCULATION OR COIL BOILERS.

105. *General Characteristics of Boilers with Limited Circulation.*—The special feature of these boilers consists in the employment of tubes rising in successive coils or folds, each one of which receives the water at its lower end, and discharges the steam at its upper end. The movement of water is thus limited to what is necessary to replace that which is evaporated, and that carried over by the steam. The steam-bubbles move through almost stagnant water, and their velocity is always low.

106. *History of the Belleville Boiler,* 1878 *type.* — The history of the Belleville boiler was for a long period practically that of the tubulous marine boiler itself.

M. Belleville was, in fact, the first to grapple with the difficult problem of the employment of tubulous boilers on board ship; and he has brought to bear remarkable perseverance and great fertility of resource to the solution of the various difficulties which confronted him at each step.

The first Belleville boilers were tried on the *Biche* in 1856; they were composed of vertical iron coils, in which the water circulated in an opposite direction to the external current of hot gases. The boiler as actually fitted is shown in Figs. 134, 134A, 134B, 134C, and may be briefly described as follows:—

The feed-water was fed into the double coil E placed at the bottom of the funnel, and which corresponds roughly

BOILER OF THE "BICHE" (1856 MODEL).

Scale $\frac{1}{40}$

Fig. 134.

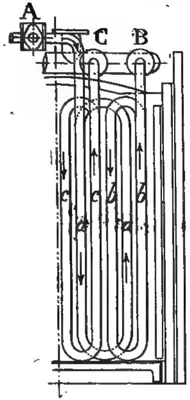
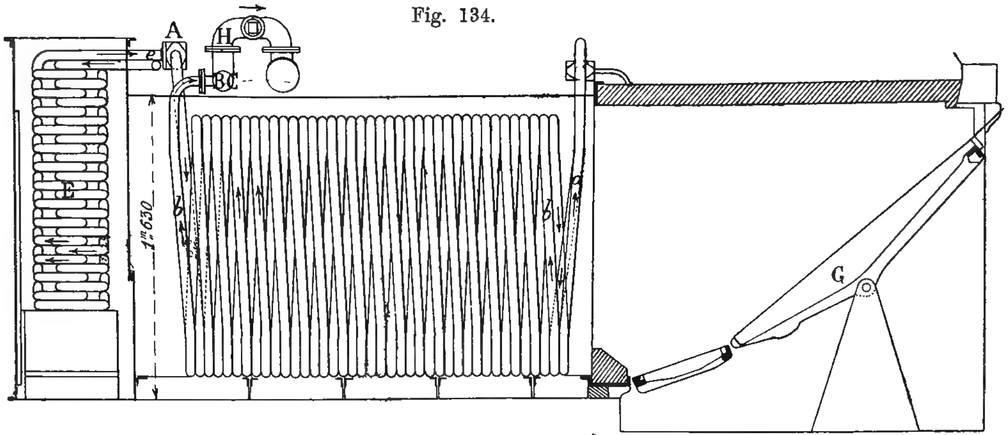


Fig. 134B.



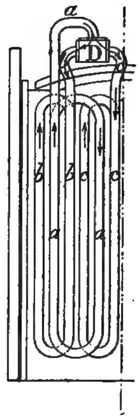


Fig. 134C.

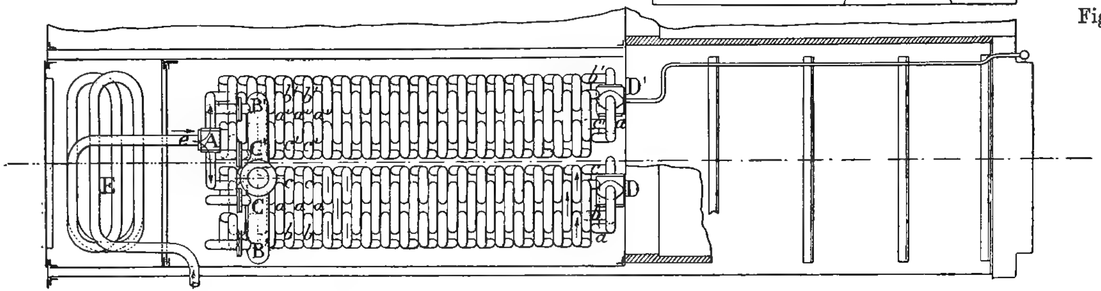


Fig. 134A.

to the economisers used in the 1896 type. On entering the actual boiler the feed water was divided in the distributing box A between the two coils a and a^1, which reached up to the grate, and it returned through the coils b c, b_1 c_1, which lead into the steam collector B C. The coils b c and b_1 c_1 served as superheaters. The several boilers deliver through the pipe H into a common steam-main. The length of tube in the economisers was 170 ft., and in the boiler proper 380 ft. The grate, much inclined, was formed of two portions, being an early form of movable grate. The trials on the *Biche* happily did not lead to any serious accidents, but the results were not satisfactory. Those of the *Argus* and *Sainte Barbe* made in 1861, on a new and more simple type shown in Fig. 135, were also unsatisfactory, but the personal qualities of the inventor were so much appreciated by M. Dupuy de Lôme and M. Mangin that they encouraged the continuance of his experiments.

BOILER OF THE "ARGUS"

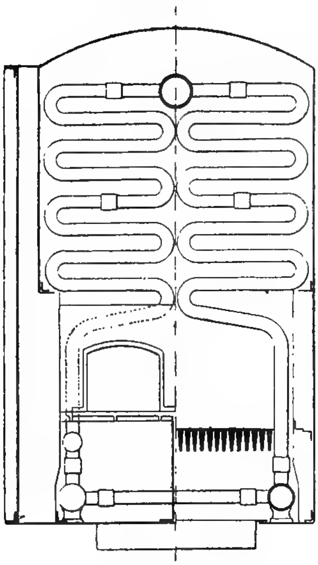
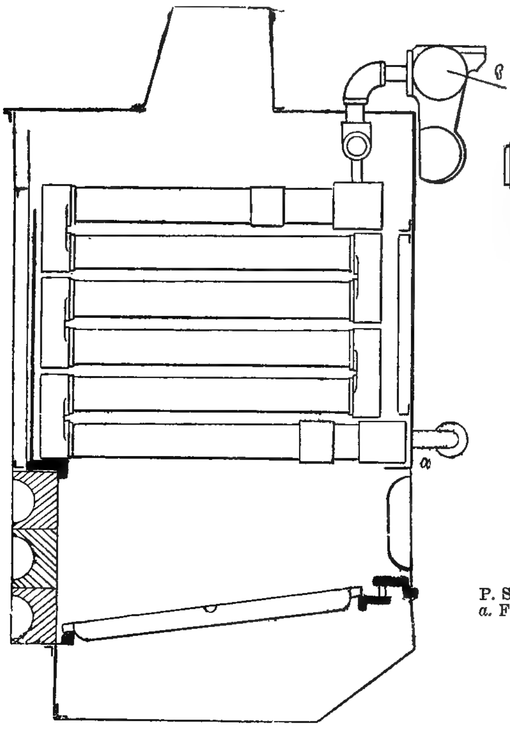


Fig. 135.

Ten years later, the Belleville boilers reappeared with coils analogous to those of the *Argus*, and composed of horizontal tubes, so arranged that the flames came first into contact with the tubes full of water and then ascended vertically among the remaining coils. The steam was taken from the upper part of the boiler by a transverse tube or collector, surmounted by a second tube, called a "separator," which communicated with the collector by very small orifices (Figs. 136 and 136A).

This arrangement was adopted to prevent priming. The new boilers were fitted to the transport *Vienne*, the despatch boat *Actif*, a few gunboats of the *Oriflamme* type, and more particularly on steam launches which at that time were coming into general use.

STEAM LAUNCH (1866 TYPE).



P. Steam outlet.
a. Feed inlet.

Fig. 136.

SEPARATOR.

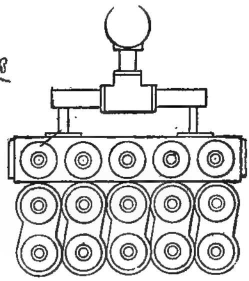


Fig. 136A.

On the launches they gave such good results that the same model, somewhat modified, has been retained up to the present day; Fig. 137 shows a boiler as at present in use.

In 1869 the Belleville boiler seemed to have been sufficiently perfected, from a constructional and general service point of view, as to justify its adoption by M. Dupuy

de Lôme on the yacht *Hirondelle*, a boat whose speed demanded the use of high pressures.

Fig. 138 gives a transverse section of the first boilers

STEAM LAUNCH (1895 TYPE).

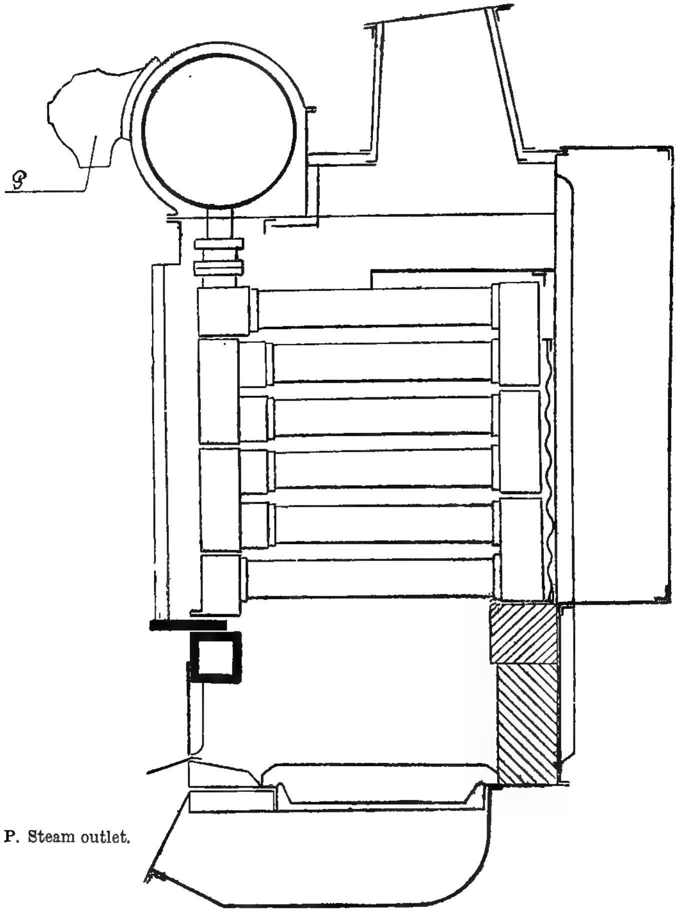
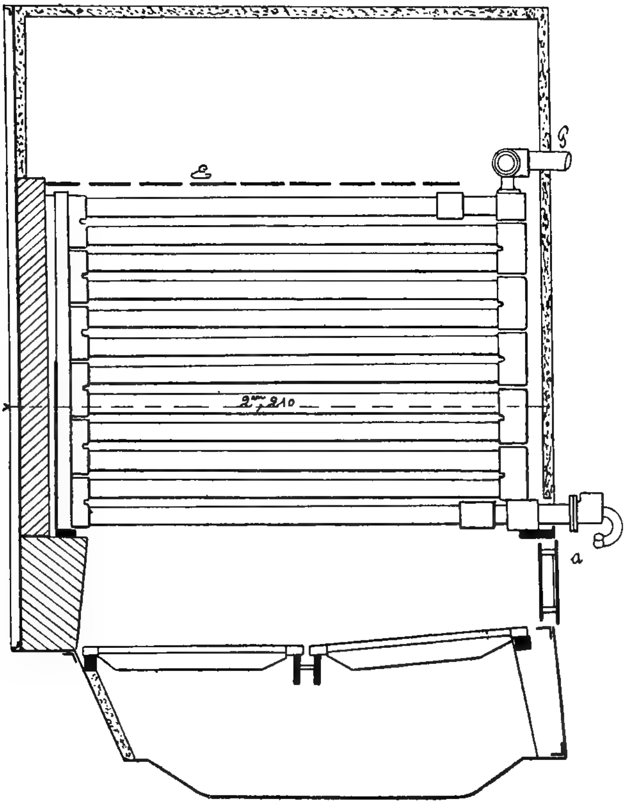


Fig. 137.

of the *Hirondelle*, and shows the feed-water collector at the bottom, and the steam collector at the top with the "separator" above it. The construction is the same as in

BOILER OF THE "HIRONDELLE" (1869)



E. Baffle. P. Steam outlet. *a*. Feed inlet.

Fig. 138.

SEPARATOR.

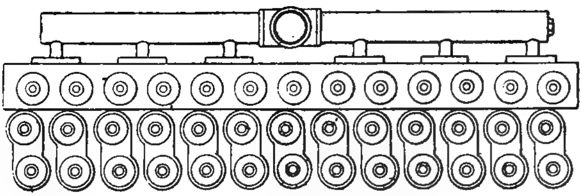


Fig. 138A.

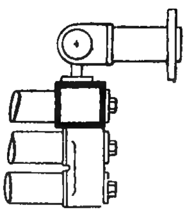


Fig. 138B.

the launch boilers, the coils being composed of horizontal tubes connected by vertical junction boxes.

The principal improvement in the *Hirondelle's* boilers was the adoption of automatic feed-regulators operated by floats such as are still being fitted to modern Belleville boilers (see paragraph 188). Automatic regulation was apparently indispensable for the maintenance of a constant level in the twelve boilers, which together only contained 115 cubic feet of water. A vertical separator was fitted to the steam-pipe for the purpose of trapping the water carried over by the steam.

In the light of present experience, the 1869 boilers would not be considered adequate for the power expected on the *Hirondelle*; nevertheless, on the 21st March 1870, a satisfactory trial was made, in which, while burning 19.9 lbs. of coal per square foot of grate, 9.3 lbs. of steam were obtained per lb. of coal, as estimated from the diagrams.

The consumption of coal per horse-power was 3.8 lbs., a satisfactory figure with non-compound engines. Subsequently, in service, these results could not be obtained, and after a year of unsatisfactory working, it was recognised that extensive alterations to the boilers were necessary.

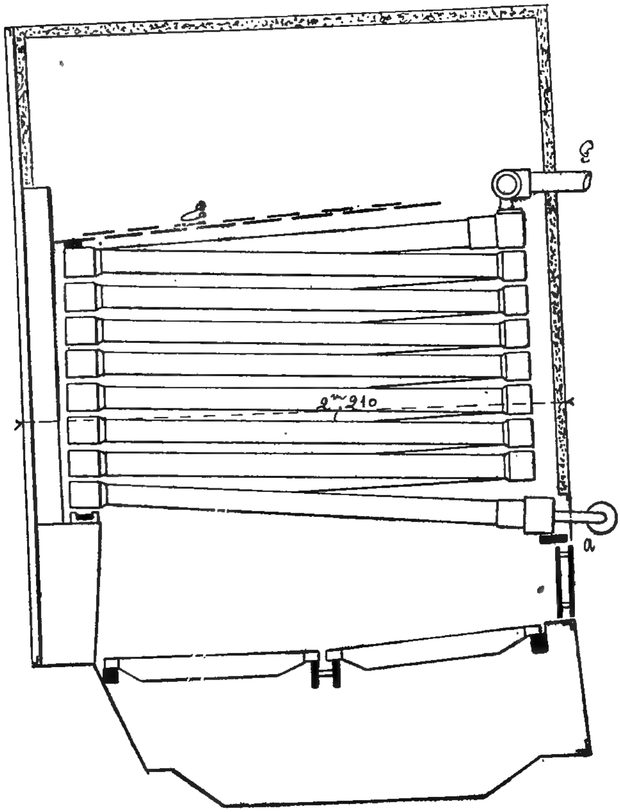
The sound portions of the eighteen original boilers were utilised in the construction of nine new ones. The second half of the set were of new design as represented in Fig. 139.

The tubes were inclined and connected by horizontal junction boxes; this arrangement facilitated the disengagement of the steam and has since been exclusively adopted. In the 1872 model the "separator" tubes were retained as being the only known means of preventing priming and regulating the output of steam. The automatic feed-regulators operated by floats were replaced by others actuated by the difference in pressure at the top and

bottom of the boiler. These worked fairly well, but their use has not since been continued.

The comparative trials between the two models of Belle-

BOILER OF THE "HIRONDELLE" (1872 TYPE)



E. Baffle. P. Steam outlet. *a*. Feed inlet.

Fig. 139.

ville boilers in 1873 are still of interest. Difficulties were there met with which should not to-day be lost sight of when making an installation of powerful tubulous boilers.

The 1869 boilers were irregular in working, owing

principally to the steam not being able to get away with sufficient freedom.

The whole of the water was at times forced up from the lower tubes, and on one occasion all the tubes in the lower rows, which were full of steam, became red hot. Further, on account of there being no steam reservoir, the slightest irregularity in working had an immediate effect on the engine-power, which oscillated between 651 and 971 horse-power. This irregularity was especially marked with thin fires; with thick fires an excessive amount of smoke was produced, 5.4 lbs. of coal were burnt per horse-power, and the funnel became red-hot.

In the boilers of the 1872 model the steam was enabled to get away with greater freedom, but other disadvantages outweighed this, and the result as a whole was not satisfactory. In order to regulate the output of steam, the total section of the separator tubes was limited to 1.18 square inches per boiler. The fall in pressure was such that with a pressure of 57 lbs. per square inch in the boiler, which corresponded to the load on the safety-valves, only a pressure of 14 lbs. per square inch was obtained at the engines. When the separator tubes were made sufficiently large to reduce the difference in pressure to 14 or 18 lbs. violent priming commenced and the fires had to be slackened. Due to the irregularity of working, the production of steam per lb. of coal remained very low. After the failure on the *Hirondelle*, M. Belleville, less discouraged than ever, came to the conclusion that his 1872 model was defective only in its details, more especially in regard to the facility for the escape of steam. He retained, therefore, the same constructive arrangements, which he has since but slightly modified, and abolished the small separator-tubes, adopting instead a steam drum or large separator. He also placed a reducing valve on the steam-pipe. This valve could be regulated at will and successfully

replaced the earlier small separator-tubes. A drain, or downtake pipe, was fitted to return the water from the separator back to the feed-collector, the water passing on its way through a settling tank where the solid deposits

BOILER OF THE "CHARLEMAGNE."

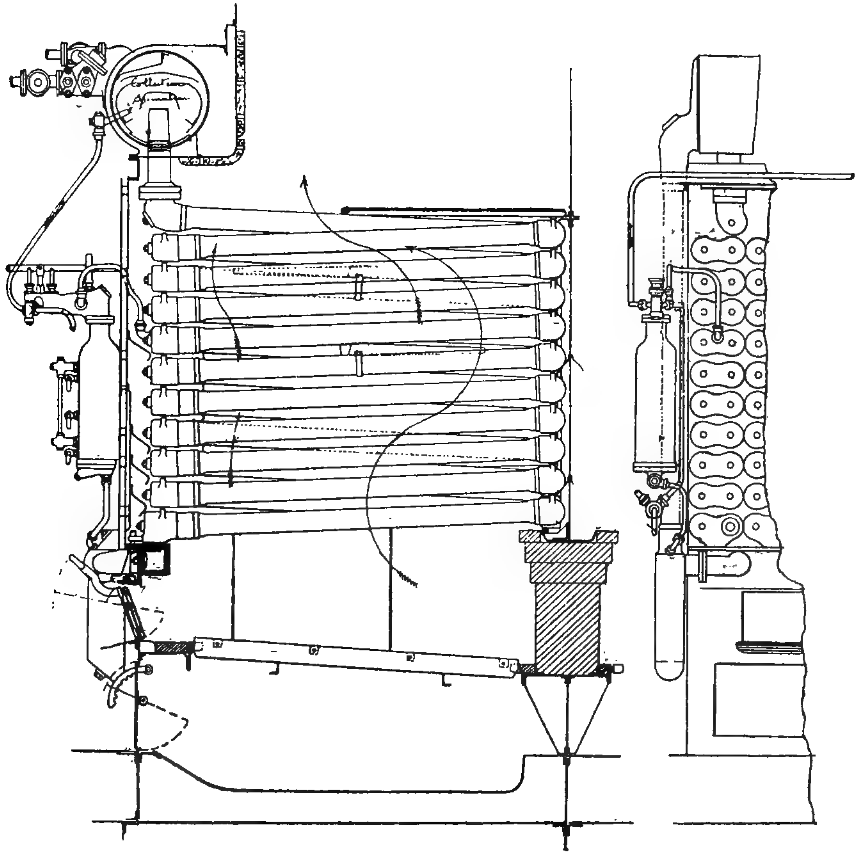


Fig. 140. Fig. 140A.

could accumulate. The embodiment of these alterations constituted the 1878 model. This new type was tried with success in 1880 on the *Voltigeur*, and soon became extensively used.

The principal applications of Belleville boilers as thus constructed are those in the French Navy on the *Rigault-de-Genouilly*, the *Hirondelle* (new set), the *Milan* (Fig. 14), the *Alger*, *Léger*, *Lévrier*, *Charner*, *Bruix*, *Bugeaud*, *Tréhouart*, *Brennus*, *Bouvet*, etc., etc. The English Admiralty tried them on the *Sharpshooter*, and has since adopted them in the *Powerful*, *Terrible*, *Ariadne*, *Arrogant*, *Diadem*, *Europa*, *Furious*, *Gladiator*, *Hyacinth*, and *Niobe*, and their example has been followed by the navies of other countries. Since their adoption on the *Ortégal* in 1884, all the steamers of the Messageries Maritimes, the *Sindh*, *Australien*, *Polynésien*, *Armand-Béhic*, etc., have been fitted with Belleville boilers. They have, in fact, been more fully tested in actual service than any other type of tubulous boiler, and their employment is therefore attended with less risk and uncertainty.

The 1878 type cannot be regarded as definitely abandoned in principle, as it is still preferred by some engineers, in spite of the advantages of the 1896 type. A detailed description is given in paragraphs 108 and 109, together with that of the later boilers with economisers.

107. *Belleville Boilers with Economisers.—Comparisons with the* 1878 *Type.*—The principal defect of the Belleville boiler, as regards its suitability for naval purposes, a defect also possessed by most boilers having free circulation, is its falling off in economy as higher rates of combustion are approached. The space above the grates is so restricted, that the flames are liable, to a certain extent, to be prematurely extinguished, and pass over the tubes in a smoky state, the result being imperfect combustion and sometimes even re-ignition and secondary combustion in the uptakes. Also the short course of the gases through the tubes is unfavourable from the point of view of thermal efficiency.

This inherent defect has been somewhat but not altogether

remedied by the use of jets above the grate—the steam jets first adopted being now superseded by jets of compressed air, (see paragraph 34), and also by skilful firing on lines which experience has shown to give the best results with these low furnaces. The first boilers of the 1878 type were only comparable in efficiency with cylindrical boilers when working at very low rates of combustion, up to 20.5 lbs., at which rates all boilers are about equal. During the trials of the *Milan* in 1884, the rate of combustion could not be increased beyond 22.5 lbs. per square foot of grate surface, the base of the funnel being heated at times above a dull red. Ten years later, on the *Bugeaud*, it was found possible, under good conditions, to burn 25.6 lbs. per square foot of grate. Since then, this rate has been further increased, the best trials on board with the 1878 type being those of the *Bouvet*, which gave the following results:—

Lbs. of coal per square foot of grate . .	22·53	29·29
Water evaporated per lb. of coal	8·54	8·03

This increase in the permissible rates of combustion has been principally due to the stirring and mixing action of the compressed air-jets.

A great improvement was made in the Belleville boiler in 1896 by the introduction of a feed-water heater or economiser of large size placed above the steam drum. There is a space between the boiler and economiser forming a secondary combustion-chamber in which the gases may re-ignite and complete their combustion before passing on to the economiser, which is then in a position to abstract the heat produced by the gases after they leave the boiler proper. Also the number of boiler tubes has been reduced, facilitating the escape of the steam and increasing the slight circulation of water accompanying it. The passage of the water in the economiser is from the bottom to the top (the opposite

direction, although perhaps more correct in theory, would seem to have involved too many risks), whence it passes to the separator and then takes its usual course to the bottom collector.

According to trials made at the St Denis works the boilers with economisers produced in round numbers at 228 lbs. pressure, 9.8 lbs. of steam per lb. of coal, at the low rate of 15.4 lbs. of coal per square foot of grate surface, and 8.9 lbs. of steam at the somewhat high rate of 31 lbs. of coal per square foot of grate. On a boiler intended for the *Marseillaise*, the combustion was pushed as far as 35 lbs., while obtaining an evaporation of 8 lbs. per lb. of coal.

The following are the results of a series of trials made with a boiler of the *Furieux* :—

Grate Area G	44·83 sq. ft.
Heating Surface	938·5 sq. ft.
Economiser Surface	548·5 sq. ft.
Total S	1487·0 sq. ft.
Ratio $\frac{S}{G}$	33·17

Lbs. of Coal per sq. ft. of Grate	8·2	15·36	21·5	30·72
Water evaporated per lb. of Coal	11·6	10·2	9.3	8·6
Steam Pressure in lbs. per sq. in.	226	227·5	231·8	234·7
Draught at base of funnel in inches of water	·205	·346	·5	·75
Temperature at base of funnel	145°C	220°C	328°C	430°C
,, of water before heating	29·6	30·7	27	26·3
,, ,, after ,,	78.1	85·6	107·4	132

At high rates of combustion, the steam carries with it into the separator, about 5 to 8 per cent. of its own volume, or from six to ten times its own weight of water. The steam, as it leaves the boiler is, however, dry.

Before passing on to a more detailed consideration of this boiler it should be mentioned that the economisers

BELLEVILLE BOILER.
(1896 MODEL).

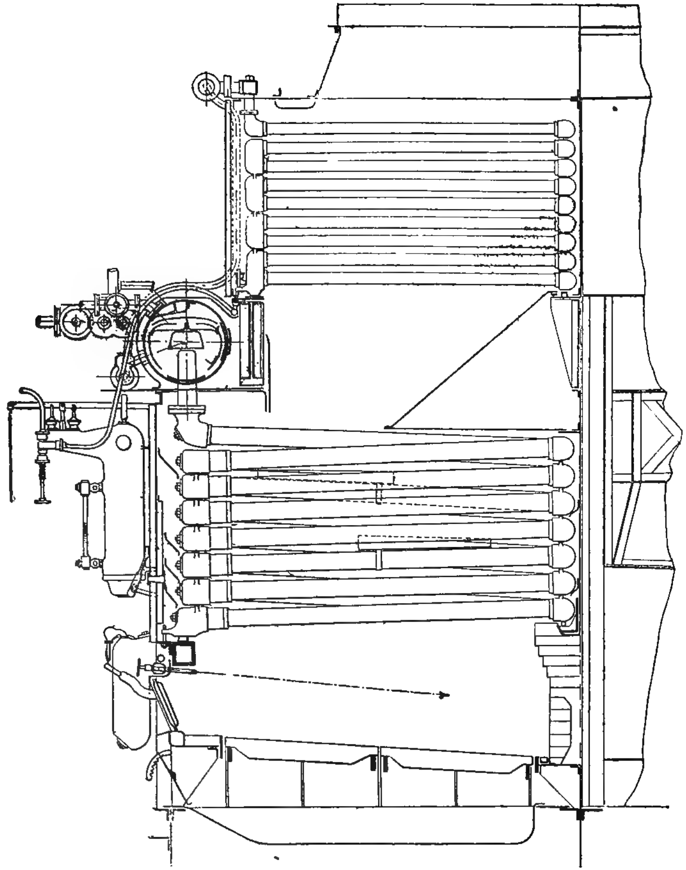


Fig. 141A.

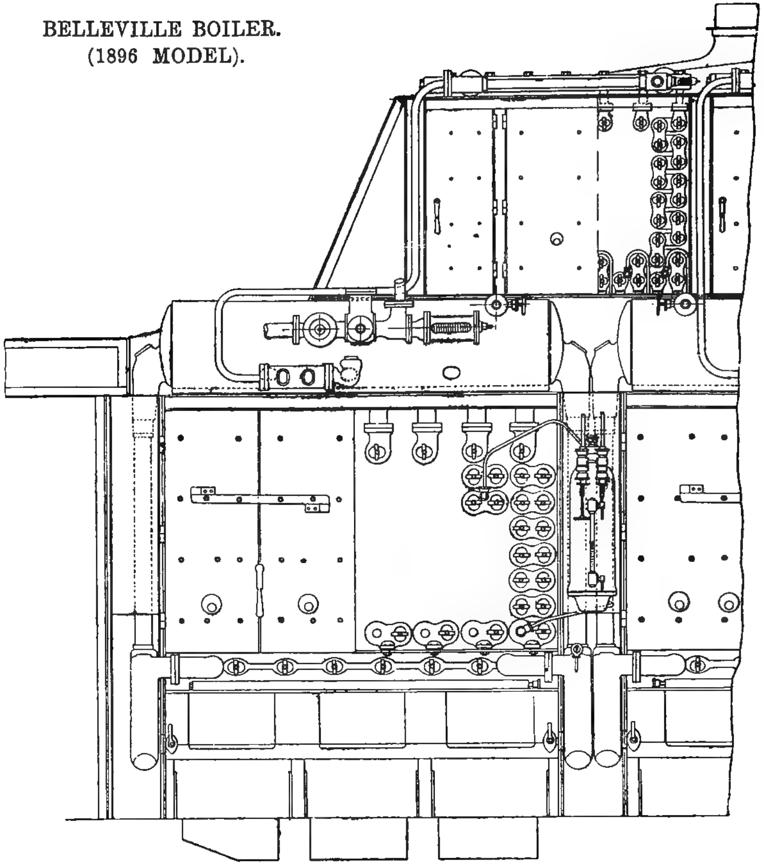


Fig. 141.

have given trouble owing to their liability to internal pitting. This may develop very rapidly, and is due to sluggish circulation, and to the fact that the economisers contain

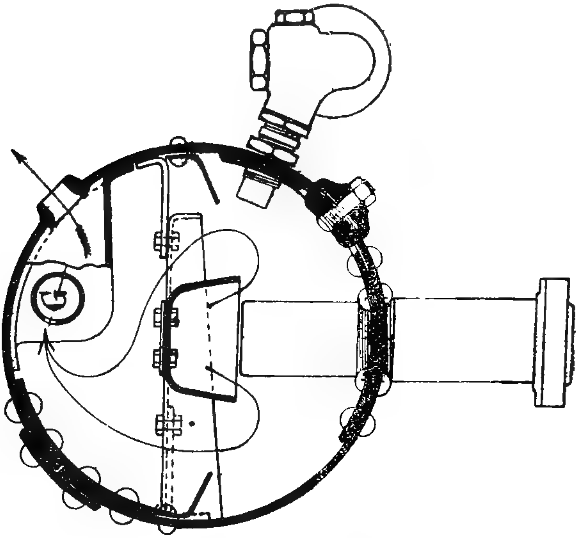


Fig. 142A.

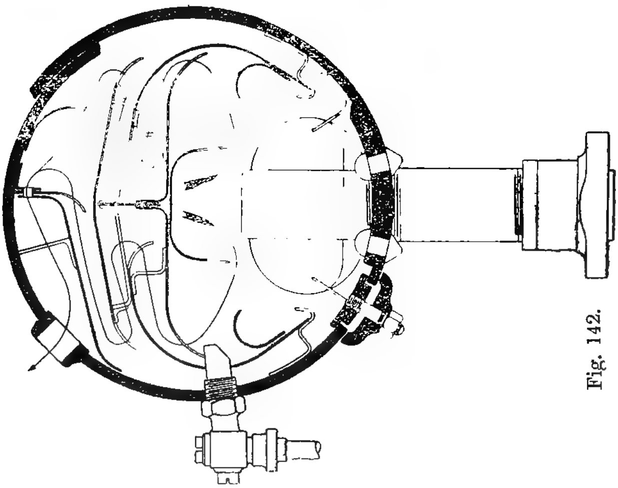


Fig. 142.

feed-water which has not been previously in circulation, and is therefore unneutralised. Strong complaints on this subject have been made in this country, accidents having been

frequent, especially on the *Europa*. The complete purification of the feed-water is certainly more necessary with economisers than without.

Also, it is difficult thoroughly to clean the soot off the economisers, owing to their inaccessibility. This must largely affect the economy which otherwise would be expected from their use. To this difficulty of cleaning the heating surfaces may be attributed the results contained in a report of the French Mediterranean Squadron, which reports in general are very favourable to the Belleville boiler. Three battleships, the *Charlemagne*, the *Gaulois*, and the *Bouvet*, of which the two first only had economisers, steamed in company from Royan to Toulon, and it was therefore possible to compare their respective daily consumption of coal. A slight advantage rested with the *Bouvet*, which had no economisers, the rate of combustion being moderate. Belleville boilers with economisers have been fitted on H.M.S. *Diadem* with satisfactory results. Sir John Durston gives the following particulars of these boilers. They are thirty in number, twenty of them containing eight generator elements and six economiser elements, six with seven generator elements and six economiser elements, and four with nine generator elements and seven economiser elements. The tubes of the generator elements are of 4½ ins. diameter, and those of the economiser elements of 2½ ins. diameter. The following are the principal data for a boiler having eight generator and six economiser elements :—

	Sq. Ft.
Grate area	49
Heating surface of eight generator elements .	995
,, ,, six economiser ,, . .	355
Total heating surface . . .	1,350
Ratio $\frac{S.}{G.}$	27·5

The heating surface of the generator portion of the *Diadem's* boilers amounted to 29,600 sq. ft., and that of the

economisers was 10,950 sq. ft., making a total heating surface of 40,550 sq. ft. On the full speed trial with open stokeholds, these boilers developed 17,262 I.H.P., with a coal consumption of 20.8 lbs. per square foot of grate.

108. *Description of the Modern Belleville Boiler.*—This boiler, as now constructed, is composed of a number of independent elements, each consisting of two vertical rows of parallel tubes inclined two or three degrees from the horizontal; those in the one row being inclined in the opposite direction to those in the other, and being connected to them at each end by horizontal junction boxes. The complete element forms in reality a flattened spiral. A boiler for a large ship would contain from nine to eleven of such elements.

In the boilers without economisers illustrated by Figs. 140 and 140A each vertical row of the elements consists of nine or ten tubes—generally ten; on the *Bouvet*, this gives a course of 118 ft. for the steam bubbles from the bottom of the element to the separator. The normal water-level, supposing the contained water to be unmixed with steam, *i.e.* free from bubbles, would be below the fifth row of tubes, or about the mid-height of the element. This water-level is indicated by the glass gauge affixed to the reservoir provided at the front of the boiler. The actual level in the tubes depends on the volume of the steam bubbles intermixed with the water, which in turn depends on the rate of evaporation. The water is distributed to the different elements by a feed-collector of box section placed over the fire-doors and running across the width of the boiler. The connections to this collector are made by means of nipples (Fig. 144) of very restricted area, the object being to insure a uniform distribution of the feed-water, and to reduce the difficulty of making a tight joint. This arrangement effectively prevents any tendency of the water to

reverse its direction of flow. The mixture of steam and water passes from the upper end of the element through a short vertical tube into the separator, the point of emission being some height above the bottom of the latter. In this separator, which is of somewhat small diameter, the water is separated from the steam, and the steam connections are mounted on the shell of the separator.

The method of drying the steam by causing the current of steam suddenly to change its direction and velocity, so as to project the liquid particles against the outside concave portions of the passages, appears first to have been applied by M. Belleville in his separators. These are fitted with internal baffle plates running the length of the drum, and of a shape in cross section which has been subjected to great variation. Fig. 142 shows the somewhat complicated arrangement adopted in 1894; the edges of the baffles are serrated. In 1901, these baffles were entirely discarded, with the exception of a sort of bonnet over the connection from the elements, and a perforated internal steam pipe was fitted.

The feed inlet D is at the end of the separator (Fig. 143). The water is sprayed into the steam space at a very high pressure, and the minute particles of water are in consequence immediately brought up to the temperature of the boiler. This arrangement was doubtless intended in the earlier boilers to produce instantaneous precipitation of the salts; in fact, up to 1884, M. Belleville hoped to be able to work with sea-water alone, thanks to this precipitation, and to the mud-drums at the bottom of the down-comers.

These down-comers consist of a large vertical tube descending from each end of the separator at F, and are for conveying the water from the separator down to the feed-collector. Their lower ends are connected to mud-boxes (Fig. 141), which form a prolongation of the down-

BELLEVILLE STEAM SEPARATOR (TYPE 1900).

Cross section on vx.

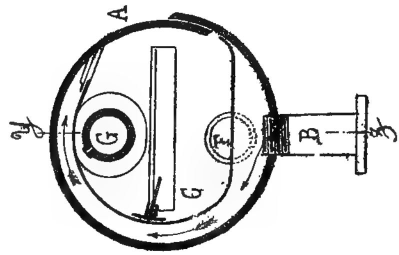
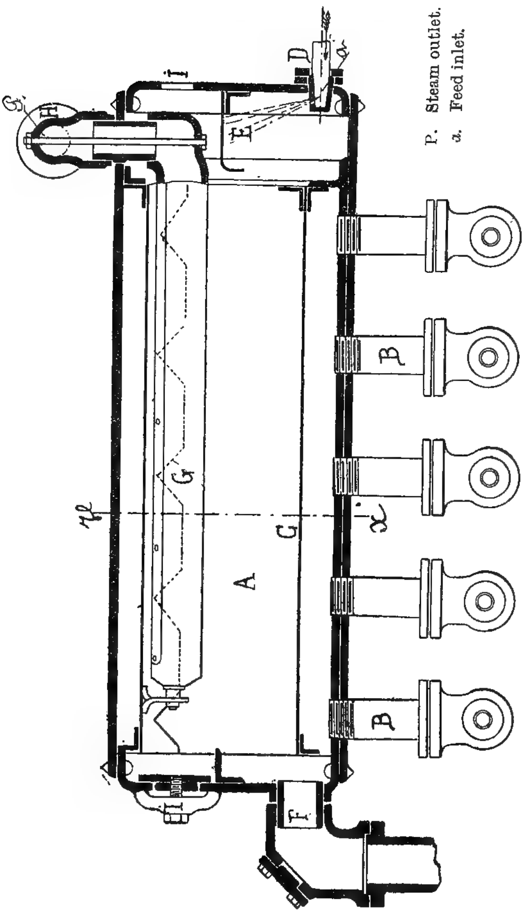


Fig. 143A.

Longitudinal section on yz.



P. Steam outlet.
a. Feed inlet.

Fig. 143.

comer. The blow-off is fitted to these mud-boxes. A non-return valve has been added to the bottom of the down-comers, so as to prevent any return movement of the water towards the separator; this valve, however, hardly seems necessary.

A small cylindrical reservoir, placed about mid-height of the elements, contains the float for actuating the automatic feed-regulator, and carries the glass water-gauges.

The course of the furnace gases will now be considered. The grate is of the usual form and construction, and the hot gases ascend vertically across the tubes. Before the adoption of economisers two horizontal baffles were fitted amongst the tubes so as to compel the gases to take a longer course. These baffles have been retained although the economisers have more effectively accomplished the same object, viz., the better utilisation of the heat.

The disadvantage of the low furnace is overcome by the energetic agitation of the gases by the compressed air-jets. These jets, which have given such good results with Belleville boilers, as indicated in the preceding paragraph, were formerly applied without success to the long horizontal furnaces of cylindrical boilers. The air is delivered at from 10 to 14 lbs. pressure by means of air-compressors which form a somewhat cumbrous adjunct peculiar to the Belleville boiler.

The adoption of economisers has led to a reduction from ten to seven, in the number of rows of tubes forming a boiler element; all the other features of the boiler, however, remain the same. The economiser is constructed in exactly the same way as the boiler, but with smaller tubes. It generally contains two elements less than the boiler, and each of these elements has one or two rows more tubes than those of the boiler; thus the boilers of the *Marseillaise* have nine elements of seven rows each in the boiler, and seven element of nine rows in the

economiser, the total length of the courses through the elements being respectively 95 and 87 ft., or a total of 182 ft.

Belleville boilers are essentially of the large tube type. One design with tubes $3\frac{1}{4}$ ins. outside diameter has been used to a certain extent in the French Navy, but is now almost abandoned. In recent warships the tubes have been entirely of $4\frac{1}{2}$ ins. diameter, spaced 1 in. apart horizontally and $1\frac{3}{16}$ ins. vertically. On the steamships of the Messageries Maritimes the tubes are $4\frac{15}{16}$ ins. diameter, with 1 in. horizontal and $1\frac{3}{16}$ ins. vertical spaces.

The economiser tubes are of $2\frac{3}{4}$ ins. outside diameter, both for the naval and merchant services, spaced $1\frac{3}{16}$ ins. apart, vertically and horizontally.

The boiler casings are of thin plates, with a lining of fire-brick around the furnace, the portions above this latter being double, with a filling of ashes or asbestos between them. Hinged doors are fitted in front of the boiler and economiser elements.

109. *Details of Construction.*—Successive improvements, introduced during a period of more than forty years, have made the Belleville boiler remarkable for the care and skill bestowed upon the design and construction of its very characteristic details. Its component parts, when new, can be put together with great facility, thus avoiding the necessity for large hatchways, as required with cylindrical boilers, and which are so often difficult to provide. When a tube gives out, the element containing it can be replaced in two hours. Should a spare element not be available, the tube itself can be replaced in four or five hours.

At the Belleville works the tubes are subjected to a most minute inspection before use. In spite, however, of all precautions, including the addition of lime to the feed-water, the tubes were formerly very liable to local pitting;

they would also occasionally show signs of failure at the weld, but in France, at least, serious ruptures due to overheating are unknown. The adoption of solid drawn tubes, cold finished, constitutes a notable advance in construction, and has greatly increased the life of the boilers.

Several fatal accidents due to tube ruptures have occurred with the boilers constructed in England.

The tubes in the bottom row are $\frac{3}{16}$ in. thick, and the remainder $\frac{5}{32}$ in. thick, the economiser tubes being $\frac{1}{8}$ in. thick.

Fig. 144 shows the connection between the elements B and the feed-collector A. The joint is made simply by the elements resting upon a small conical nipple screwed into the top of the collector, a thin nickel ring being interposed to facilitate the making and breaking of the joint. Security is assured by the tee-headed bolt shown.

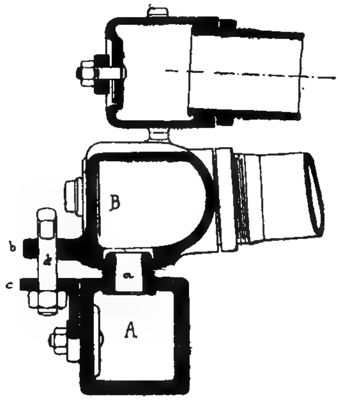


Fig. 144.

The elements are connected to the separator by flange joints, the flanges being rectangular with four bolts.

The junction boxes shown in Fig. 144 are now of malleable cast-iron, although steel castings were formerly used. They are provided with inspection doors or hand-holes opposite the front end of each tube; the joint being internal, the door is held up by the pressure in the boiler, and tightness with ordinary care is thus insured. The danger inherent to the external doors, at one time permitted, now no longer exists.

The tube ends are screwed externally, the present method of attachment to the junction boxes being as follows:—Short pieces of tube or nipples are permanently screwed into the

junction boxes, the ends of the tubes, properly so called, butt against these, and are united to them by an external sleeve or socket, screwed over both, and secured by a back nut, red lead being applied before tightening up. The construction is, in fact, similar to that of an ordinary screwed socket joint. The threads in the boxes and on the nipples are made to a slightly different pitch so as to insure a tight joint.

These joints hold well, but unfortunately cannot be undone after being some little time in service; the socket can never be removed intact, and must be cut through with a chisel. This is why it takes much longer to replace a tube than a complete element.

Further particulars relating to the construction and working of the modern Belleville boiler will be found in *Mecanique à l'Exposition de 1900*, by M. Ch. Bellens, and in the *Revue Technique de l'Exposition de 1900*, by M. Boutté. In this latter book will be found in particular (Plate 29) the complete results of trials made with economisers at St Denis.

110. *General Features and Durability of Belleville Boiler.*— Comparisons of the relative durability of various types of boilers present exceptional difficulties because of the very different treatment and care demanded by them. In contradistinction to the engines whose construction permits of no great variation, any particular boiler requires a preliminary training of the stokehold staff, and also a knowledge of certain characteristics on the part of the commander. This fact explains the diversity of opinions as regards the Belleville boiler in France and in England.

In France the Belleville boiler was only placed in the hands of a *personnel* familiar with its use, after the lapse of some considerable time, sufficient even for the introduction and development of rival types. It was never a question of a monoply or the exclusive use of the Belleville boiler. The reports of the engineers in charge only became uniformly

favourable after other somewhat similar types had been tried and used. This experience is somewhat similar to what has occurred in this country. The tone of the last report of the Boiler Commission is very different in regard to the Belleville boiler from their first preliminary pronouncement.

In England after its sudden and almost universal adoption, three or four years' experience brought to light all the peculiarities and weaknesses observed in France from 1880 to 1900. Also in addition several unfortunate accidents occurred hitherto unknown in France; it is not therefore surprising that the exaggerated favour at first shown was quickly followed by an equally disproportionate condemnation. Thus it happens that by a curious coincidence the Boiler Commission, appointed by the Admiralty, reported the Belleville boiler as being deficient in durability and almost dangerous in use, at the same time that the latest reports of the French Navy described them as the most reliable and as requiring the least attention.

Similar contradictions are to be found in the statements of the Chief Engineer of the Messageries Maritimes and of those English shipowners who for a time adopted the Belleville boiler, such as Messrs Wilson of Hull, and Messrs Peterson of Newcastle.

In fairness, the Belleville boiler should be judged in the light of experience gained with boilers constructed at Messrs Belleville's works, and placed in charge of properly trained stokers. Under these conditions we find no such defects as those observed on the *Hyacinth* during her comparative trials with the *Minerva*, when the water lost by leakage at the boiler joints amounted to 1.25 per cent. of the total feed.

It is also necessary to discriminate between those features —good and bad—which are peculiar to the Belleville boiler, and those which are now shared by other types. The liability to pitting especially noticeable on the English *Diadem* and the French *Milan* is to a certain extent common to all types of

water-tube boilers, and has even given trouble with cylindrical boilers since the abandonment of brass tubes. Ability to withstand high pressures and light weight per unit of grate area are, in the naval work, no longer the monopoly of the Belleville boiler; in this latter respect comparisons with later types will be found in Chapter XIV.

For service on land, where weight is of little consequence, the principal advantage claimed for the Belleville boiler has been that it is inexplosible. In this respect they are still superior to other types, by reason of the small diameter of their steam drums, the small volume of water, and especially their great flexibility. The tubes are capable of resisting pressures up to 850 lbs. per square inch, and the separators up to 285 lbs. with stresses not exceeding 4 or 4½ tons per square inch.

The effect of an explosion—the first examples of which occurred on the English ships *Terrible* and *Mutine*—is minimised by reason of the small volume of steam liberated; thus in the accident which occurred on the *Terrible*, the 13th March 1889, although a tube opened out for a length of more than 3 ft., only one stoker was killed and three injured; and on the *Mutine*, the 19th December 1900, a similar accident resulted only in the death of one stoker and injury to another; on the 15th October 1898, during a shore trial of one of the *Argonaut's* boilers, a joint, improperly bolted, gave way, causing injuries to five men, but no fatalities. Finally, the great freedom for expansion and deformation possessed by the elements is such that the bending of the lower tubes, which sometimes is very pronounced after prolonged service, does not injuriously affect the joints; also it allows the fire to be pushed from the moment of lighting up, steam to be raised quickly, the rate of firing to be suddenly varied, and the fires drawn without in any way humouring of the boiler.

On no account, however, should this security from explosion lead to the neglect of ordinary precautions. Long

before the accidents on the *Terrible* and the *Mutine*, due to obstructions of saline deposits in the tubes, it was known that the Belleville boiler could not be worked with sea-water. The escape of steam where a tube has become simply pitted through has more than once caused serious injury to the stokers on opening the doors forming the front casing.

It may be said in a general way that the construction and working of Belleville boilers, while not exactly requiring specialists, demand a preliminary practical training both on the part of the workshop and stokehold staffs. This remark applies less to the boiler itself than to its mechanical accessories—the automatic feed-water regulators, the steam reducing valves, and the air compressors—which are more indispensable to the Belleville than to any other type of boiler, on account of the insufficient volume of the combustion-chamber, the absence of a clearly defined water-level, and the very small capacity of the steam drum.

The Belleville is the only type of water-tube boiler which has been in service afloat for a period exceeding the usual life of a cylindrical boiler, and which therefore can furnish data concerning the relative durability of the new types. It should, however, be recognised that no exact determination of its qualities in this respect is possible, as the various parts wear very unequally. The replacement of any damaged portion is so easy that the defects are remedied as they occur and the boiler renewed piecemeal. Thus the cruiser *Voltigeur* and the mail packet *Ortegal* still carry their original boilers after more than twenty and sixteen years' service respectively; and the same may be said of the mail boat *Australien*, after 800,000 miles steaming. An official enquiry made by the naval authorities into this latter case disclosed the fact that at the overhaul carried out after each voyage, a number of elements were replaced amounting annually to 5 per cent. of the total

in the ship. This credits the tubes with an average life of about twenty years. The feed-collectors rarely require replacing, but the conical nipples only last eight or ten years, and the nickel rings eight months. The mud-boxes last about as long as the feed-collectors, but often require repairing. The ashpans require replacing after about six or eight years, and repairing about every three years.

The above results agree fairly well with those observed in the French Navy, thus the boilers of the *Léger* and the *Lévrier* have had 72 per cent. of their elements replaced in nine years.

111. *Weight and Space occupied.*—Previous to the adoption of economisers, Belleville boilers, for large vessels, weighed .536 tons per square foot of grate surface, including water and accessories. Some of the earlier installations, such as the *Alger*, weighed a little more, the more recent ones, as the *Pothuan*, being a little lighter. In the latter case the actual weight showed a saving of 35 tons or 11 per cent. below the estimate.

The adoption of economisers has not altered the weight per square foot of grate, which for the *Saint Louis* is .5 tons, and for the *Marseillaise* .485 tons, but it has made an appreciable reduction in the weight per horse-power, owing to the increased power developed per unit of grate area.

The weight per I.H.P. is the factor which most concerns the naval architect. The early types of Belleville boilers without economisers, which always worked under natural draught, could not develop more than 11 H.P. per square foot of grate area, with engines as then constructed weighing .595 tons per square foot of grate, representing 120 lbs. per I.H.P. Good cylindrical boilers, as fitted on board the *Sfax*, could give with the same engines 18.3 I.H.P. per square foot of grate under a moderate forced draught; their weight of .915 tons per square foot of grate being

thus equivalent to 12.15 lbs. only per I.H.P. Although at the present time the use of heated air has provided cylindrical boilers with a veritable economiser, yet at the same time the adoption of forced draught has enabled the weight per I.H.P. to be progressively reduced. Economisers have therefore become more than ever necessary to Belleville boilers if they are to succeed in competition with cylindrical boilers on board passenger ships.

The classification which has been made when treating of cylindrical boilers between those parts whose weight depends on the pressure, those which depend on the rate of combustion, and those whose weight depends solely upon the size of the boiler as represented by the grate area, is not exactly applicable to water-tube boilers.

The tubes, which largely compose the first portion, would not need to be increased in weight to withstand double or triple the pressure to which they are subjected. This remark is peculiarly applicable to Belleville boilers which contain only one vessel of any importance, and that of but small size. However that may be, the same classification has been observed in the tables of No. 173, wherein are given the weights of the different parts of Belleville boilers so as to have figures corresponding to those given for cylindrical boilers.

112. *Special Advantages of a Limited Circulation.*—Before leaving the subject of boilers of limited circulation, it is important to observe that in them the direction of the current of water, as well as its intensity, can be regulated at will. As a consequence it is possible to cause the water to travel in a contrary direction to the flame, and thus to place the coldest part of the boiler in contact with the cooler gases. The hot gases can, therefore, be more completely deprived of their heat than is the case in tubulous boilers of other systems.

This important property seems to have been taken into consideration at the outset by M. Belleville, and to have inspired the arrangement of his first boiler, represented by Fig. 134. Also the flow of water throughout every portion of the boiler is, with limited circulation, positive, regular, and uniform.

These advantages would be perfectly realised in a boiler consisting of a single coil. Their great defect is due to the small quantity of water in circulation. This water having got rid of its air and part of its salts, serves to dilute the feed-water and reduce its corrosive tendency.

It is imperative that only very pure water should be used. Boilers of this kind are necessarily simple in principle, and the varieties proposed remain, up to the present, very limited, only two being worthy of note; those consisting of a single coil, generally of helical form, and those comprising a number of separate coils arranged side by side. Boilers of the former type were constructed in France by Isoard about 1849, by Loftus Perkins, and were for some time (about 1878) adopted by Herreschoff, and by Thornycroft in 1883; this type has now been abandoned.

There remains the multiple coil type, composed of straight tubes connected end to end in the same plane, the first example to appear being the Blakey boiler of 1774. To-day the Belleville is the only representative of the type, at east on board ship.

The petroleum-fired boiler, of Colonel Renard, has also a limited circulation, and in it the gases of combustion might theoretically be cooled down to the temperature of the feed. This last boiler, of extraordinary lightness, is intended for aerial navigation, and therefore does not properly come within the scope of this treatise.

CHAPTER XII.

BOILERS WITH FREE CIRCULATION.

113. *Early Types with Free Circulation.—Principles Embodied.—M. Joessel's Work.*—The difficulties experienced in attempting to overcome the irregularity in the working of the first Belleville boilers, led to the introduction of various fittings with this object in view. The principal defects of the Belleville boiler were the insufficiency of the water circulation, which allowed steam to collect in the lower rows of tubes, and the excessive priming, due in a great measure to the absence of a steam-chamber, which rendered the engine-speed extremely irregular.

The typical "free circulation" boiler may be described as consisting of inclined generating tubes connecting two flat vertical water-spaces, the whole having the appearance of a Martin-Cochrane boiler reversed. The boiler is surmounted by a steam-drum, in which is maintained the working level of the water.

A boiler of this type was constructed at Indret, in 1869, by M. Joessel, a well-known French engineer, who, in 1862, had commenced experiments on the effects of heating the feed-water and of superheating the steam. His boiler of 1869 was of curious construction, the large upper reservoir forming quite a boiler in itself, and the water-tubes presented the peculiarity that they contained concentric smoke-tubes which ran the entire length of the boiler, and so offered a double heating surface. The furnace gases

rising around the generating tubes passed through short stay tubes in one of the flat water-spaces into a smoke-box on the outside, from whence they returned by the smoke-

SHOP BOILER SIMILAR TO THAT OF TUG *PISTON*.

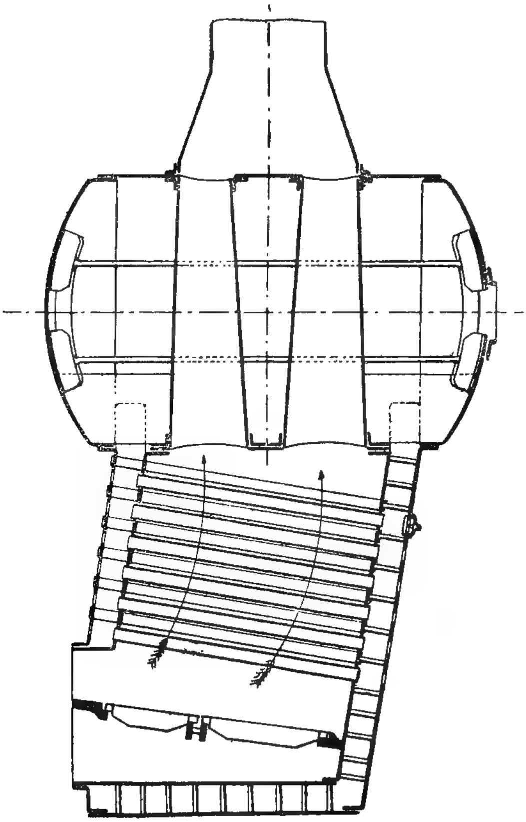


Fig. 145.

tubes to another smoke-box at the opposite end of the boiler outside the second flat water-space, in a similar manner to the gases in the boiler described in paragraph 132. Thus, as often happens, the first boiler of the type was

very complicated in design ; yet it worked for a long time on a steam-launch between Indret and Nantes.

M. Joessel, continuing his experiments, soon simplified the boiler by abandoning the internal smoke-tubes. A boiler on this design was proposed in September 1871, but rejected ; another for the tug *Piston* was approved in 1874, and the following year this same type was adopted for the despatch-boats *Actif* and *Argus*. All these boilers were in active service, and worked satisfactorily. Fig. 145 represents one of a battery of land-boilers constructed in 1875. One of them was repaired in 1888 and placed on board a launch, and is probably still in service. The flat plates of the water-spaces were strongly stayed together, and hand-holes were provided opposite the ends of each tube for the purpose of inserting and expanding the tubes, and for cleaning and inspection.

The steam-chamber was of very large capacity, and had, passing vertically through it, large tubes, by which the hot gases rose to the chimney. The back water-space was continued forward underneath the fire-bars in a horizontal direction, and formed the bottom of the ashpan, thus complicating the construction without any corresponding increase in efficiency.

As the practical difficulties of construction and management appeared to have been overcome, it was decided to ask the inventor for a design for the boilers of the *Colbert*, then in course of construction, but he was of opinion that his boiler was not yet sufficiently perfected, and therefore discouraged this proposed important application. M. Joessel was, in particular, dissatisfied with the premature cooling of the flames which (as in the Belleville boilers) was due to the insufficient height of the tubes above the grate.

He considered the provision of a combustion-chamber between the grate and the tubes indispensable, but he never succeeded in putting this idea into practice. His

experience in the working of boilers led him to realise the nature and importance of the difficulties to be overcome. As M. Joessel never patented his inventions—a great loss to marine engineering—it is rather difficult, after twenty years, to ascertain the exact part he played in the invention and development of tubulous boilers with flat water-spaces; it is, however, well known that he did play for several years a most important part in the development of this type of boiler.

114. *Penelle Boiler.—Cadiat Boiler.*—This boiler, introduced in the steam pinnaces of the French Navy towards 1874, is a Joessel boiler in which the flat plates opposite the tube-ends are replaced by others of spherical form. The upper part of these dished plates forms the ends of the steam-drum, the barrel of which is connected to the two inside tube-plates.

The absence of man-holes for the replacing, cleaning, and inspection of the tubes was a source of difficulty. The Penelle boiler, after being in service for several years, has been abandoned, but this type of boiler was revived by M. Cadiat, with some improvements, in 1875, and has since then been in service with good results at Toulon.

115. *Oriolle Boiler.*—Amongst the various types of different water-tube boilers now in service, the Oriolle boiler most nearly approaches one of M. Joessel's early designs, more especially intended for torpedo-boats. It has been adopted with success on the steam-boats of the Loire, where, to prevent smoke, coke is exclusively used as fuel. The use of fuel giving a very short flame effectively overcomes the difficulty caused by the insufficient height of the combustion-chamber. The Oriolle boiler, the application of which has been very limited, may well be described before considering other types with free cir-

culation, of which several were introduced contemporaneously with those of Joessel in 1870-1872.

In the Oriolle boiler, the flame passes immediately in among the lower tubes, which are 2 ft. $3\frac{1}{2}$ ins. above the grate; two vertical rows of tubes are arranged at each side so as to form the sides of the furnace.

Combustion, with a good air-pressure on board some of the torpedo-boats, was sufficiently active to enable 61.4 lbs. of coal to be burnt per square foot of grate, but, as feared by M. Joessel, the production of smoke was then so excessive as to betray the presence of the torpedo-boats from afar. M. Oriolle has attempted, without success, to get rid of the smoke by washing the gases in a kind of water-injector placed in the base of the funnel.

The water-level is in the tubes; with a total of twenty rows of tubes, the four or five upper ones are entirely full of steam, and the three or four immediately below are, on account of their inclination, partly filled with steam and partly with water. The Oriolle boiler can therefore only be said to have free circulation over a portion of its tubes. A steam-drum is placed above the back water-space, sometimes parallel with the boiler front, and away from the hot gases, as on the *Lansquenet*, and sometimes perpendicularly, as on the torpedo-boats 75 to 81, 83 to 86, and 161 to 163 (Fig. 146), but always without communicating with the front water-space.

On the *Lansquenet* the tubes are of small size—1.6 ins. internal diameter and 0.08 in. thick; this rendered possible a tube-surface thirty-nine times the grate area, and a total heating surface about forty-three times that area.

The tubes were first simply expanded into the tube-plates; but latterly the Caraman joint has been used (paragraph 92, Fig. 102). There are no hand-holes opposite the tubes, and therefore the replacing of a tube necessitates the taking apart, or rather, the demolition of, the water-

chambers. The flat plates of the water-space are stayed; some of the stays are formed of tubes, so as to allow of the insertion of the steam-jets used for freeing the generating tubes from soot. These tubular stays involve the omission of about one tube in twelve.

The first Oriolle boilers were fitted, towards 1890, in the

ORIOLLE BOILER (TORPEDO-BOATS, 161 TO 163).

Half end elevation. Half transverse section. Longitudinal section.

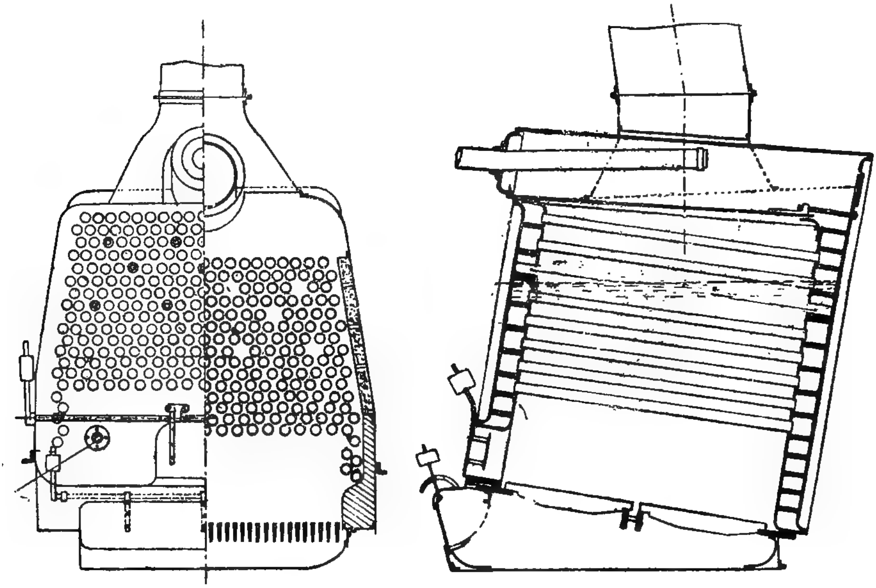


Fig. 146. Fig 146A.

Tubes marked thus ◎ are suppressed to facilitate cleaning.

torpedo-boats 75, 80, 81, 83, 84, and completed three years' service without requiring any repairs. In 1893, nearly the whole of the steam-tubes required replacing, but the water-tubes were still in good condition. The steam-tubes had to be condemned on account of the pitting occurring beneath a deposit resulting from the introduction of sea-water as "make-up," which sometimes culminated in perforations,

M. Haas took the opportunity thus presented of making the investigations described in paragraph 82 on the formation of hydrochloric acid. Oriolle boilers have been recently fitted in the *Zouave*, the *Turco*, the *Doudart-de-Lagrée*, and in the torpedo-boats 161, 162, 163. The efficiency of the Oriolle boiler was best shown during the speed-trials of these last torpedo-boats. The boilers have 48.4 sq. ft. of grate area, and the speed obtained slightly exceeded twenty-one knots, while burning about 61.4 lbs. of coal per square foot of grate. The power developed was not ascertained, but it can be deduced from the particulars known, supposing the power proportional to the cube of the speed. The following table is thus obtained :—

Number of Torpedo-boat . . .	161	162	163
Coal burnt per square foot of grate per hour	62·19	58·11	62·60
Corresponding total—			
Horse-power	1,132	1,234	1,082
Coal per horse-power-hour . . .	2·66	2·28	2·88

The Oriolle boiler is remarkably light, the total weight—water and fittings included—is, according to M. de Maupeou only 0.256 ton per square foot of grate.

MM. Brosse and Fouché have patented a boiler which, in many respects, resembles the Oriolle boiler; the water-level is in the tubes, but much nearer the steam-chamber, and the tubes are divided into two parts, the lower ones being 2.16 ins. outside diameter, and the upper ones 1.77 ins.

An angle-iron baffle, placed in the front water-space, causes the steam from the lower rows of tubes to pass towards the outside, so as not to obstruct the free exit of steam from the upper rows. A similar baffle is placed in the back water-space. Another departure from the Oriolle boiler is the direct passage of the steam from the front water-

space into the top drum, and the return of the water into the back water-space by large tubes, analogous to the down-takes of the Du Temple type of boiler.

116. *D'Allest Boiler.—Successive Types.*—Tubulous boilers, with flat water-spaces, are, at present, principally represented in the French Navy by the D'Allest boiler. This boiler was introduced about the same time as that of M. Joessel,

BARRET-LAGRAFEL BOILER (1870).

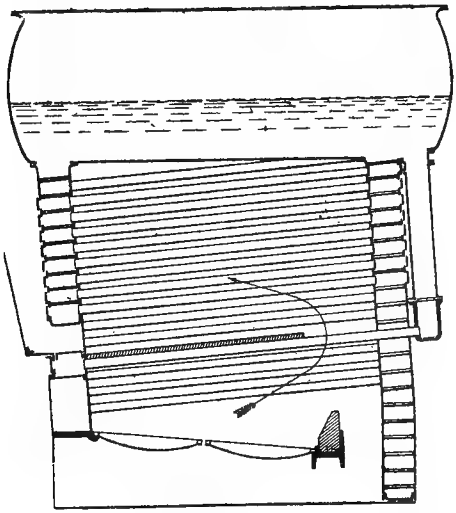


Fig. 147.

and, as now made, embodies the improvements patented in France by MM. Barret and Lagrafel in 1870-71, and Lagrafel and D'Allest in 1888. From the first these boilers were of similar construction to the present D'Allest boiler, except as affecting the direction of the hot gases. In the first model, the gases passed once backwards and forwards amongst the tubes, a brick baffle being arranged for this purpose at about one-third the height of the nest of tubes (Fig. 147).

In 1871 the horizontal baffle was replaced by a vertical one

BARRET-LAGRAFEL BOILER (1871).

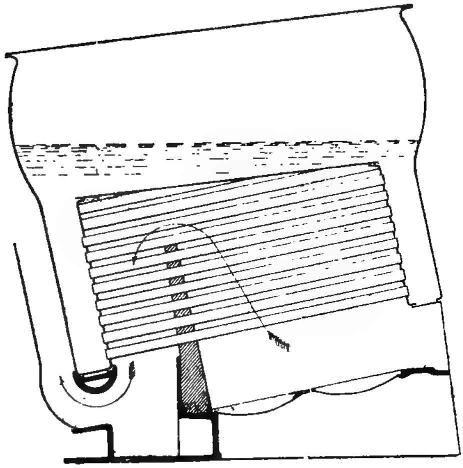


Fig. 148.

BARRET-LAGRAFEL BOILER (1872).

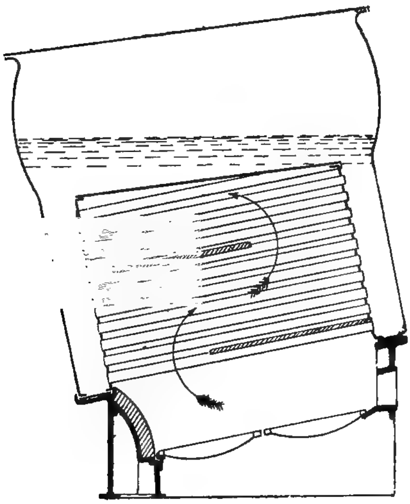


Fig. 149.

of bricks, extending above the fire-bridge, which caused the gases to take an up-and-down direction (Fig. 148).

Subsequently, in 1872, the horizontal baffles were again adopted, two, however, being used—one immediately above the fire, the other arranged about two-thirds up the tube-plate, as shown in Fig. 149.

This latter arrangement secured a better combustion of the coal at the back of the grates.

In all these arrangements of baffles, the utilisation of the heat had in general received much more attention than the question of securing a perfect combustion. The boiler patented in 1888, and which we have principally to consider, is, on the contrary, so arranged as to secure a good combustion. This is obtained by the use of a large combustion-chamber, where the flames are thoroughly mixed prior to their entering in amongst the tubes. Barret and Lagrafel boilers were fitted in 1871 on the *Isère*, in 1873 on the *Blidah* and the *Médéah*, and later on the *Paoli*, the *Spahi*, the *Colon*, the *Kabyle*, and other steamers of the Compagnie Fraissinet. The D'Allest model of 1888 made its appearance in 1891 on the *Liban* and the *Don-Pedro*. As a result of the trials of these steamers it has been largely adopted in the French Navy. It is the only model which we shall consider at length, and is met with on the *Bombe*, the *d'Iberville*, the *Bouvines*, the *Jemmapes*, the *Jauréguiberry*, the *Carnot*, the *Charles-Martel*, the *Masséna*, the *Foudre*, the *Chasseloup-Laubat*, the *d'Assas*, the *Cassini*, the *Casabianca*, and the *Guichen*.

117. *General Arrangement.—Space Occupied.*—The flat water-spaces and the generating tubes which unite them are slightly inclined backwards so as to cause the steam to be directed towards the front. The patent anticipates the use of curved tubes, with the ends normal to the vertical tube-plates; but this construction, designed to permit the free

GUICHEN.

LAGRAFEL AND D'ALLEST BOILERS.

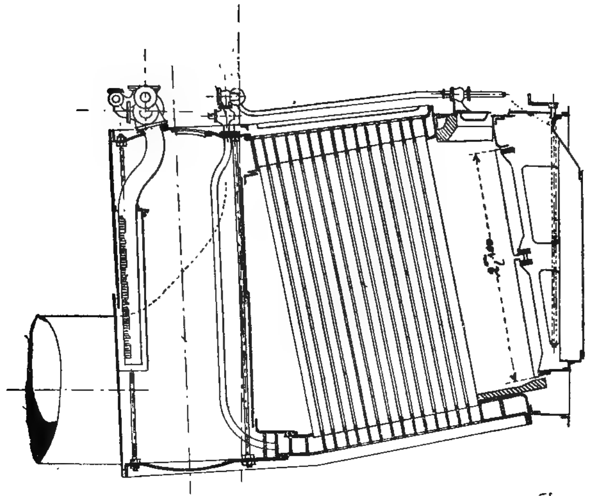


Fig. 150A.

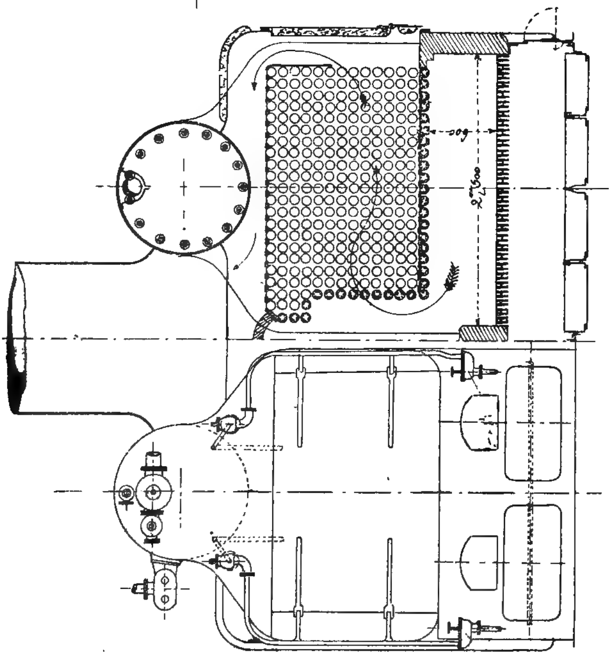


Fig. 150.

expansion of the tubes, has not been applied in practice. Above the generating tubes is a large cylindrical reservoir connecting the two flat water-spaces. The working level is in this reservoir, which serves principally as a steam-chamber and separator.

The fire-box or combustion-chamber which constitutes the characteristic feature of the D'Allest model of 1888, is situated at the side of the grate. A baffle of bricks resting on the bottom row of tubes directs the flame into the combustion-chamber, from whence it returns across the generating tubes, taking about the same direction as in a cylindrical return-tube boiler. The opening for the escape of the hot gases is placed among the lower rows of tubes, and leads into a smoke-box at the side of the boiler opposite to the combustion-chamber. The space occupied by the tubes and the combustion-chamber is closed at the top by a second baffle resting on the highest row of tubes. Below this upper baffle there are a few rows of tubes in the combustion-chamber so as to prevent it extending upwards to the top of the nest of tubes.

The direction given to the hot gases, although conducive to high efficiency, introduces a conspicuous element of danger, the gravity of which has been proved by the series of accidents that have occurred—on the *Liban* in 1890, on the *Don-Pedro*, and finally, on the *Jauréguiberry* in 1896. The hottest portion of the furnace gases comes directly into contact with the upper tubes, which are never so effectively cooled by the circulation as the lower ones, and are liable to be filled with accumulations of steam, or even to run short of water, as a result of an accidental lowering of the water-level. Since the accident on the *Liban*, the necessity of reducing the height of the combustion-chamber has been recognised, and the four upper rows of tubes are now carried across it instead of two rows as previously (Figs. 151 and 152).

Each boiler is double, having two furnaces, two sets of

tubes, two steam-drums, and one combustion-chamber, in the centre, common to both furnaces.

Owing to the great length of this combustion-chamber, equal to the length of the grates, its transverse width may be small and directly proportional to the width of the grate. The arrangement of the furnace and combustion-chamber has of late been somewhat varied, as shown by the two

BOMBE.

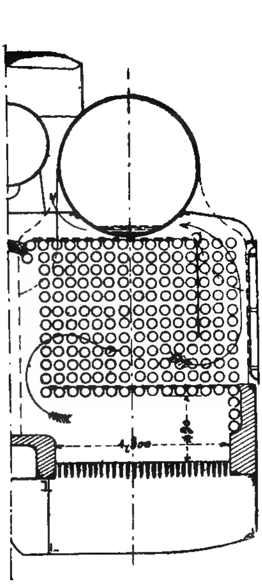


Fig. 151.

D'IBERVILLE.

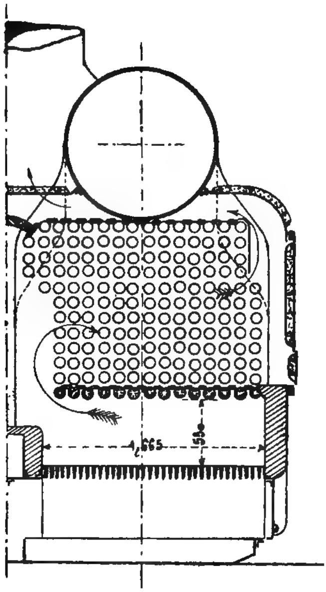


Fig. 152.

figures 151 and 152, the first representing the boilers of the *Bombe*, the second those of the *d'Iberville*. At first greater attention was given to directing and mixing the current of hot gases; but subsequent efforts have been principally directed to a reduction in the floor space occupied. On the *Bombe* the space occupied is 2.06 times the grate area, and on the *d'Iberville* it is 1.48 times, this latter figure being even lower than for the Belleville boiler. The height for the

D'Allest boilers is about 12 ft. 9½ ins. for those having thirteen horizontal rows of tubes, and about 12 ft. 5½ ins. for those having twelve rows; these are the ordinary dimensions, and are rarely exceeded.

Taking the *Jemmapes* as an example, the tube surface is 31.5 times, and the total heating surface 33.5 times, the grate surface.

118. *Constructive Details of the D'Allest Boiler.*—This boiler, simple in character, has only undergone slight variations in construction, and no fittings of a special character are used. Since the first trials of the *Bombe*, in order to prevent the hogging of the tubes which then took place, Serve tubes have been adopted for the bottom horizontal row and for the vertical row at the side of the combustion-chamber. After the first few runs the bottom tubes of the *Bombe* took a permanent curvature, the rise at the centre reaching 0.39 in. (For an explanation, see paragraph 98, Fig. 128.) This sign of fatigue taking place at the outset raised suspicions as to the durability of the boiler. The tubes


Fig. 153.


Fig. 153A.

are of steel, 3.15 ins. outside diameter and 0.12 ins. thick, and are simply expanded into the tube plates. Weldless tubes have been exclusively adopted since the opening of a badly welded tube on the *Jauréguiberry*.

The flat plates of the water-spaces are strongly stayed together, and the outside ones are provided with hand-holes opposite each tube.

After various trials two kinds of jointing were adopted at Indret for the hand-holes, one of asbestos, with a thin metal covering (Fig. 153), and the other entirely of metal (Fig. 153A).

The first-mentioned joint is composed of asbestos, tightly enclosed between two sheets of lead, with an edging of thin copper; the second is formed of a copper ring or washer between two lead ones, the three rings forming one complete washer.

The top drum is much weakened where the lower half of its circumference is cut away to form connection with the flat water-spaces, and therefore the two ends are stayed together by longitudinal stays arranged in a circle around the inside of the barrel. A curved baffle is fixed inside the drum, between the internal steam-pipe and water-level; it acts as a steam separator, in much the same way as those in the Belleville boiler, but is much simpler in form. This arrangement was adopted after the trials of the *Bombe*, whose boiler gave very wet steam.

The feed is introduced into the back water-space, as may be seen on reference to Fig. 150A, which shows the boiler of the *Guichen*. The gauge column is placed on the front water-space.

As the water-level is more stable in a gauge-glass, when the bottom tube is connected with the back-water space, since the accident on the *Liban* in 1890, the bottom tube of the gauge-glass has been carried to the lower part of this space.

It has also been decided since this accident to fix a fusible plug to the upper row of tubes, but a more accurate knowledge of the variations occurring in the water line, together with the amended bottom connection of the gauge-glass, and other improvements have diminished the importance at first attached to this supplementary precaution. The boilers of the *Jauréguiberry* do not appear to have been fitted with fusible plugs.

The steam on its way from the boilers to the engines passes through a reducing valve.

119. *Distortion of the Water-Level in the Boiler.—Circulation in*

the Tubes.—The rush of all the steam from the generating tubes into the front water-space produces a tumultuous movement of the water in this space and a big wave or surging in the top drum, whilst the water in the back space remains tranquil. This gives rise to a distortion of the water-line, which varies with the rate of working, and is of great importance. Fig. 154 shows this distortion observed from an experimental D'Allest boiler provided with windows.

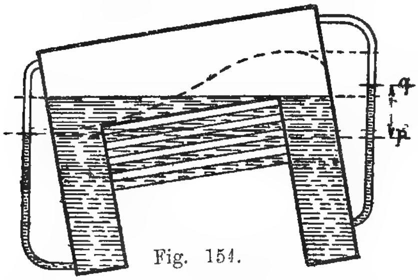


Fig. 154.

Gauge-glasses fitted to the front and back water-spaces of this boiler showed the difference in pressure existing in the bottom of these water-spaces. This difference, though much less than that corresponding to the highest and lowest points of the water surface, was, however, very appreciable—amounting to from $2\frac{3}{8}$ to $2\frac{3}{4}$ ins., the highest point being at the front, as shown in Fig. 154. From these trials some interesting conclusions may be drawn, which in part are applicable to all types of boilers with free circulation.

At the outset it should be noted that the water-levels observed during the above-mentioned trials were taken at the outside plates of the water-spaces, and not at the tube-plates, where they may have been slightly different. With this reserve, it is, nevertheless, demonstrated that this disturbance of the level causes an increase of pressure in the front water-space, which tends to retard the circulation.

The movement of the water and steam contained in the tubes is due to the reduction in the specific gravity of the liquid in the tube, and to the difference in height of the two ends of the tubes.

It may thus occur that in some of the rows of tubes there is practically no circulation at all, and in this

condition of stagnation "pockets" of steam may be formed. Hence it is by no means impossible that certain tubes should be exposed to the risk of burning, although there may have been no shortness of water. The additional pressure in the front water-space could be avoided by preventing the distortion of the water-level, which could be effected by fitting in the steam-drum either a horizontal baffle, or a sieve of the Buettner type, as on the Biétrix-Leflaive boiler. But by obstructing the upward current in the front water-space there would be the risk of increasing rather than reducing the pressure. In fact, the problem of regulating the direction and velocity of the circulation in the lower, middle, and upper rows of tubes of a boiler with free circulation is a very difficult one, owing to the small hydrostatic head available.

120 *Results Obtained.—Accident on the Jauréguiberry.*— Experiments made with a trial boiler at Marseilles gave the following results :—

Coal Burnt per Square Foot of Grate per hour. lbs.	Water Evaporated per lb. of Coal.	
	Old Type (without Combustion Chamber).	New Type (with Combustion Chamber).
8·19	..	10·67
15·36	6·06	10·42
20·48	6·53	..
24·99	..	8·02
30·92	..	8·75

The great superiority of the new type is in some measure due to the hot gases giving up a greater portion of their heat prior to entering the funnel; the temperature at the base of the chimney during the trials was 570° Fahr., with the old type, having two horizontal baffles, and 480° with the new type. Completer combustion, as shown by the analysis made

with the Orsat apparatus, accounted for the increased efficiency. With the old type, carbon-monoxide was given off in such abundance that M. D'Allest thought the carbonic acid was decomposed by contact with the cold tubes, according to the simple but hardly probable reaction,

$$CO_2 = O + CO.$$

With the new type, carbon-monoxide was traceable in small quantities above the bridge, but to a quite inappreciable extent in the smoke-box.

The substitution of D'Allest for locomotive boilers on the *Bombe* has given satisfactory results. The two sets were of the same total weight, with a notable difference in the grate areas: 77.5 sq. ft. for the original locomotive boilers, and 101 sq. ft. for the D'Allest boilers. At the most, 1,306 horse-power could be got out of the original boilers, burning 2.87 lbs. of coal per horse-power; whereas the new boilers were much more economical, although supplying steam for 1,959 horse-power.

——	*Bombe.*	*Cassini.*	*Chasseloup-Laubat.*	*Jemmapes.*
1. *Coal consumption Trials.*				
Boiler pressure . lbs. per sq. in.	125·0	163·5	171·5	159·3
Pressure at reducing valve „	114·61	151·05	135·58	166·98
Expansions $\Delta = \frac{D^2}{i\,d^2}$ . . .	4·39	8·6	12·59	11·86
Coal burnt per sq. ft. of grate lbs.	21·07	20·11	10·85	14·71
Coal burnt per horse-power . „	2·09	1·81	1·48	2·0
2. *Speed Trials.*				
Boiler pressure . lbs. per sq. in.	139·74	195·57	184·9	203·82
Pressure at reducing valve „	119·47	171·95	159·88	184·88
Expansions $\Delta = \frac{D^2}{i\,d^2}$ . . .	3·78	6·84	7·34	8·763
Coal burnt per sq. ft. of grate lbs.	48·25	31·27	23·88	30·12
Coal burnt per horse-power . „	2·37	1·94	1·77	2·10

Several ships fitted with D'Allest boilers have already made their trials: the *Bombe* with compound engines, the *Jemmapes*, *Chasseloup-Laubat*, *Bouvines*, *d'Iberville*, *Cassini*, *Casabianca*, *Jauréguiberry*, *Carnot*, and *Charles-Martel*, all with triple-expansion engines.

Practical experience with these boilers, under ordinary working conditions, has been obtained on the passenger vessels of the Compagnie Fraissinet at moderate and regular rates of working, but the boilers fitted to ships of war have not yet seen much service. The boilers of the *Bombe* alone have been at work for some few years. When inspected in 1894, the lower tubes were found to be curved in the same way as those of the boiler tried on land in 1891, without, however, causing any accident. All the tubes were bent away from the flames, following the principle illustrated by Fig. 128. The tubes also showed a tendency to wear away on the insides near the ends, as shown by Fig. 155; from this cause over seventy tubes on the *Bombe* had to be replaced during a period of two years.

The serious accident which occurred at the official trials of the *Jauréguiberry* has emphasised in an unpleasant manner the close and constant attention to the water-level, which, on the D'Allest boiler, is necessary, owing to the form of the combustion-chamber. An iron tube badly welded, or perhaps not welded at all, which had, nevertheless, been subjected to severe tests, opened out; it was the tenth tube, counting from the top, in the vertical row at the side of the combustion-chamber. As at this moment there was neither a very active fire nor a high pressure of steam, the over-heating which led to the accident was evidently due to shortness of water. Probably the level had not fallen so low as the tenth row of tubes, but it was sufficiently low to stop the circulation through the top drum, and as the

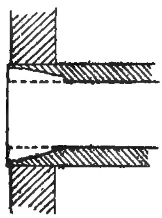


Fig. 155.

only return for the water to the back water-space was by way of the upper tubes, the result was comparative stagnation, permitting the formation of steam-chambers and the overheating of some of the rows of tubes, amongst which was the one containing the defective tube.

Since this accident no new warships have been fitted with D'Allest boilers, but the existing installations have remained at work without serious accidents. The boilers of the *Jauréguiberry* worked satisfactorily for five years. The *Guichen* has just finished a very arduous commission on the China station, without reporting any mishap to the boilers, excepting a few small blow-holes in the tubes of the lower row.

On the two mail packets *Nord* and *Pas-de-Calais* the D'Allest boilers have been for several years in very active work.

Other types of boilers embodying the same general features, such as the Babcock & Wilcox boiler, are coming more and more into use, proving that the system of free circulation in its most simple form with two water-spaces united by slightly inclined generating tubes, is still in use afloat. On land numerous types on this system are to be found; at the Exhibition of 1900 were to be seen Biétrix-Leflaive, Mathot, Roser, Steinmuller, Fitzner-Gamper, and Simonis-Lauz boilers, which differed only in details from the Babcock & Wilcox, and which are described in the article by M. Boutte on steam boilers in the *Revue Technique de l'Exposition.*

121. *Babcock & Wilcox Boiler.*—The Babcock & Wilcox boiler is one of the earliest water-tube boilers, as it dates back to the year 1868. It was almost entirely used for land purposes until the year 1889, and during this period many modifications in the design were carried out, but with these

we are not concerned in this volume, which deals with marine boilers.

In 1889 the first marine boiler was constructed for a small vessel, and the development since then, for marine purposes, has been very rapid, as evidenced by the fact that

BABCOCK & WILCOX BOILER.

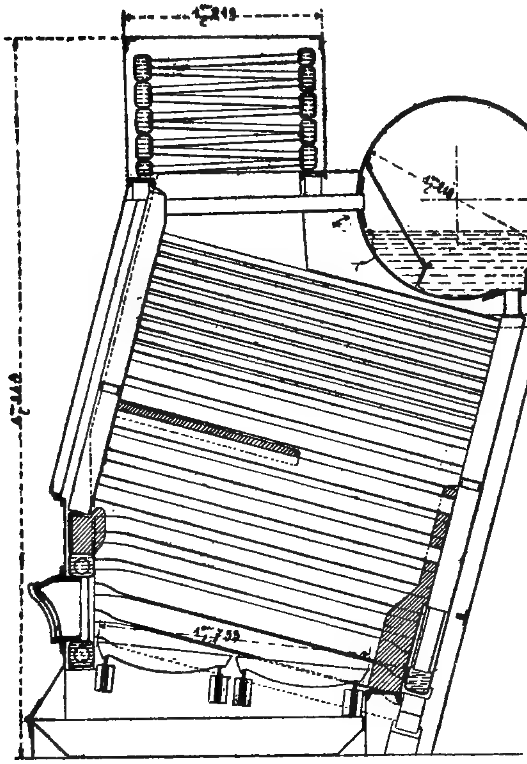


Fig. 156.

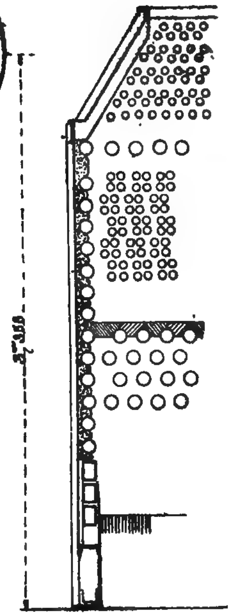


Fig. 156A.

at the present time there are over two hundred vessels belonging to all branches of the Navy and Mercantile Marine fitted with this class of boiler, amounting in the aggregate to about 1,000,000 H.P.

Messrs Thomas Wilson, Sons & Co., of Hull, fitted a

Babcock & Wilcox boiler on their small steamer *Nero* of 500 H.P. in 1895, and since then eight other vessels belonging to this firm have been fitted with these boilers, including the *Hero*, shown in Figs. 156 and 156A. One of the most important installations was on board the ss. *Martello*, which is fitted with four Babcock & Wilcox boilers, having a total heating surface of 10,740 sq. ft., a total grate surface of 200 sq. ft., and a working pressure of 220 lbs. per sq. in. The boilers were installed in place of four cylindrical boilers, and resulted in a saving of weight, by the adoption of water-tube boilers, of about 100 tons. The vessel was tried in August 1900, and since then has been regularly employed in Transatlantic service.

The Admiralty Committee on naval boilers had the *Martello* under their inspection for a period of fourteen months, and found that the boilers had stood the test of usage in the mercantile marine well. At the time the Committee inspected the *Martello*, she had run about 91,000 miles since the water-tube boilers had been put in, and the only repairs required had been those of ordinary upkeep of any boiler, such as fire-bars, brick-work, etc. The Committee also inspected the Babcock & Wilcox boilers fitted in the *Numidian*, *Buenos Ayrean*, and *Turret Cape*, and remarked that though, in the case of the last-named vessel, the boilers had been in use seven years, and had not been as well looked after as they would have been in the navy, yet their condition when examined was satisfactory.

Boilers of the marine type are usually fitted with tubes $3\frac{1}{4}$ ins. in diameter, but in many cases where the weight has to be reduced below the limit of the above type, an alternative type of boiler is used, with 4-in. tubes in the two bottom rows, and $1\frac{7}{8}$-in. tubes in the rows above (see Fig. 157). This type of boiler is the one most favoured for naval purposes.

For mercantile purposes this boiler has up to the present

been mainly used in vessels of moderate power, running up to 5,600 I.H.P., but very large installations have been provided in vessels for naval purposes, up to 27,000 to 30,000 I.H.P.

BOILER OF U.S. CRUISER *ALERT.*

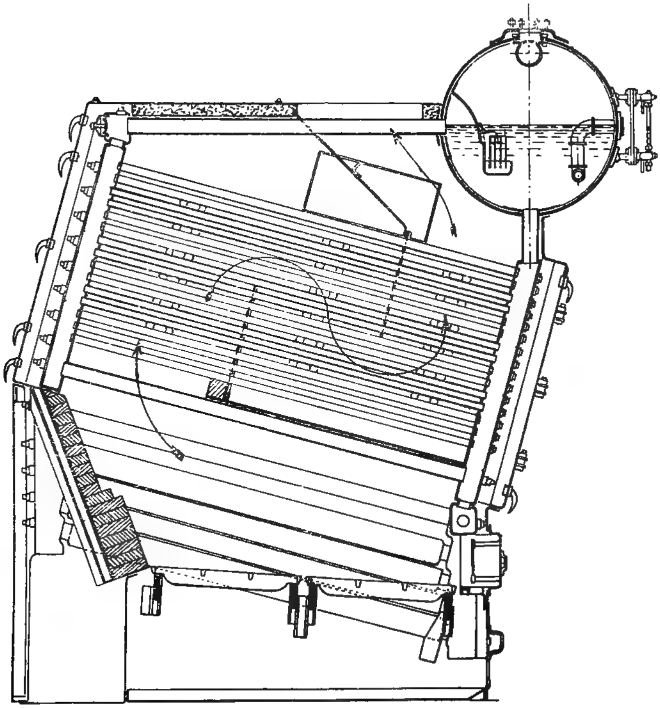


Fig. 157.

In the English Navy the first installation fitted was on the torpedo gunboat *Sheldrake*, where the contractors undertook to supply a boiler which would burn coal at the rate of 40 lbs. per sq. ft. of grate per hour, and evaporate 9 lbs. of water per sq. ft. of heating surface per hour.

Evaporative tests on shore of one of the *Sheldrake's* boilers gave the following results:—

Number of boilers in use	1
Duration of trial	3 hours
Coal consumed per sq. ft. of grate per hour . . .	40·7 lbs.
Water evaporated per lb. of coal from and at 212° .	9·16 ,,
Water evaporated per sq. ft. of heating surface from and at 212°	9·5 ,,

The installation consisted of four boilers. After the boilers were placed on board ship, a series of trials was carried out by the Admiralty, with the vessel alongside the quay, with the following results:—

Number of boilers in use	2	2	2	2
Duration of trial	8	8	8	8
Coal consumed per sq. ft. of grate per hour lbs.	15·0	15·0	25·0	25·0
Heating surface . . . . . sq. ft.	4,551	4,551	4,551	4,551
Water evaporated per lb. of coal from and at 212° . . . . lbs.	12·7	12·7	10·9	11·3
Water evaporated per sq. ft. of heating surface from and at 212° . . lbs.	5·29	5·29	7·56	7·80
I.H.P. of main engines	1,116	1,292	1,761	1,873
Coal consumed per I.H.P. per hour . lbs.	1·69	1·46	1·78	1·67

The vessel was then sent to sea to carry out a series of trials corresponding to the original conditions of contract for a vessel of this type; the results are indicated in the attached table:—

Description.	Natural draught.	Full power ½-in. air pressure.
Duration . . . . .hours	8	3
Number of boilers	4	4
I.H.P.	2,651	4,092
I.H.P. per sq. ft. of grate	10·4	16·65
Heating surface per I.H.P. . . . . sq. ft.	3·43	2·22
Coal per sq. ft. of grate per hour . . . lbs.	14·8	25.35
Coal per I.H.P. per hour . . . . lbs.	1·42	1·58

The ship was then ordered to carry out a series of trials each of 1000 miles duration, at various speeds, using three out of four boilers.

The results of these trials are given in table attached :—

H.M.S. *SHELDRAKE* WITH THREE BOILERS OUT OF FOUR IN USE.

Distance run . . . . . Miles	1,006·4	1,002·5	1·018	1,009·6	1,004·7	1,006	991·2	1,007·2	993
Duration of trial . . . . hours	69·0	68·0	70·0	68·5	67·0	66·5	59·0	61·5	567
I.H.P.	1,503	1,506	1,534	1,538	1,828	1,838	2,032	2,042	2,245
I.H.P. per sq. ft. of grate	7·9	7·9	8·0	8·1	9·6	9·6	10·6	10·7	11·8
Heating surface per I.H.P. . sq. ft.	4·54	4·53	4·45	4·44	3·73	3·71	3·36	3·34	3·04
Coal consumed per sq. ft. of grate per hour . . . . lbs.	12·7	12·6	14·0	12·9	15·4	16·1	16·6	16·7	19·2
Coal per I.H.P. per hour . . . lbs.	1·61	1·60	1·75	1·59	1·60	1·68	1·57	1·56	1·63
Number of boilers in use	3	3	3	3	3	3	3	3	3
Pressure of steam in boilers lbs. per sq. in.	120	120	135	130	137	140	145	140	150
Revolutions per min.	196·6	196·9	198·1	196·8	210·2	209·2	219·7	220·2	224·3
Speed by log. . . . . . kts.	14·7	14·7	14·5	14·7	15·2	15·1	16·8	16·3	17·4

The next two vessels were the *Espiégle* and the *Challenger*, which were shortly afterwards followed by the *Hermes*, from which ship the Belleville boilers had been removed, and Babcock boilers of the same power and the same weight, substituted.

The *Hermes* was subsequently subjected to a severe series of tests by the Boiler Committee, when an efficiency of 81 per cent. was obtained, and the Babcock & Wilcox boiler was reported as suitable for naval purposes.

Since then a large number of H.M. ships have been fitted with this type of boiler, either alone or in conjunction with cylindrical boilers, among others the following: *Sheldrake* (4,000 I.H.P.), *Espiégle* (1,400 I.H.P.), *Odin* (1,400 I.H.P.), *Challenger* (12,500 I.H.P), *Hermes* (10,000 I.H.P.), *Queen* (15,000 I.H.P.), *Cornwall* (22,000 I.H.P.), *Dominion* (18,000 I.H.P.), *King Edward VII.* (18,000 I.H.P.), *Commonwealth* (18,000 I.H.P.), *Argyll* (21,000 I.H.P.), *Hindustan* (18,000 I.H.P.), *Black Prince* (23,500 I.H.P.), *Duke of Edinburgh* (23,500 I.H.P.), *Britannia* (18,000 I.H.P.), *Hibernia* (18,000 I.H.P.), *Africa* (18,000 I.H.P.), *Lord Nelson* (16,750 I.H.P.), *Minotaur* (27,000 I.H.P.), *Dreadnought* (23,000 I.H.P.).

The type of boiler now mostly used for naval purposes is indicated in Fig. 157, which shows the boiler of the U.S. cruiser *Alert*. It will be seen that it is provided with two rows of 4-in. tubes at the bottom, the upper rows being $1\frac{7}{8}$ ins. diameter, and the gas baffling is on the vertical system.

PARTICULARS OF BOILERS OF U.S. CRUISER *ALERT*.

Grate surface (G)	47·90 sq. ft.
Heating surface (S)	2,125 ,,
Ratio $\frac{S}{G}$	44
Weight of boiler complete and dry	46,416 lbs.
,, ,, with water	54,566 lbs.
Boiler pressure	218 lbs. per sq. in.
Maximum consumption per sq. ft. of grate surface on trial	41·8 lbs.
Water evaporated from and at 212° Fahr. per lb. of coal	9·48

BABCOCK & WILCOX BOILER—MARINE TYPE.
(WITH CASING COMPLETE).

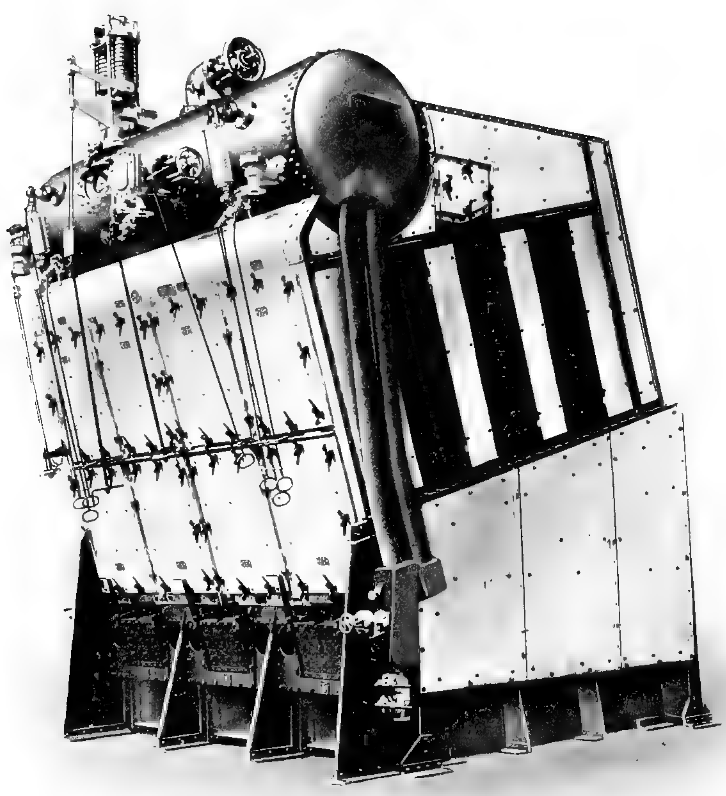


Fig. 157A.

[*To face p.* 365.

BABCOCK & WILCOX BOILER—MARINE TYPE.

(WITH CASING REMOVED).

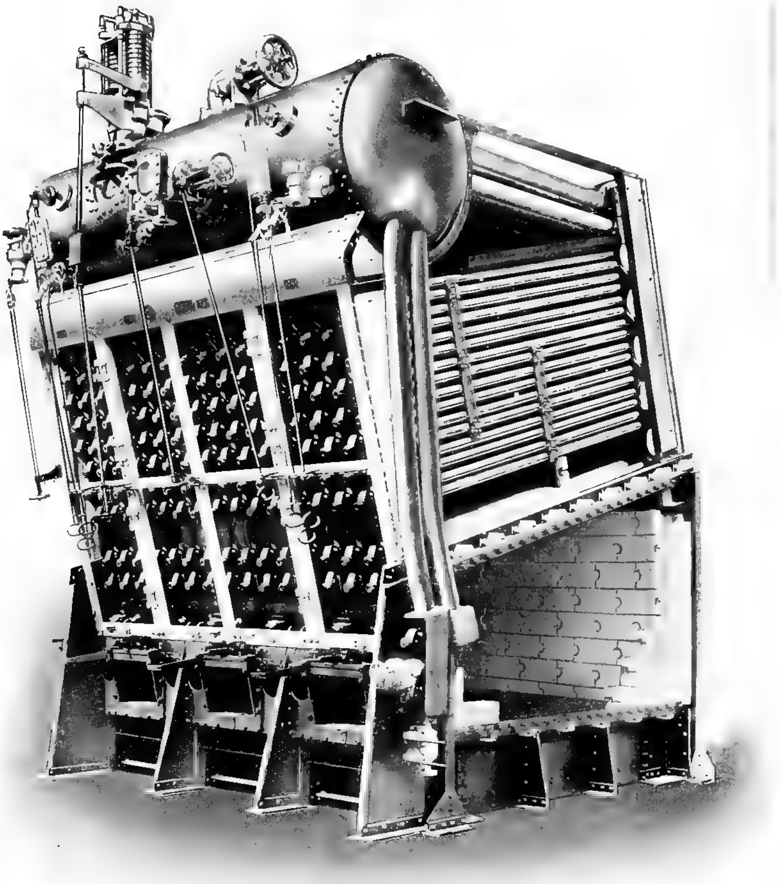


Fig. 157b.

[*To face p.* 365.

Figs. 157A and 157B illustrate the naval type of boiler with and without the casing.

The following table gives the particulars of the trials and the recorded coal consumption of some of the principal vessels. In examining these results it must be borne in mind that the machinery averages a water consumption of $18\frac{1}{2}$ lbs. of water per I.H.P., and therefore that the boiler efficiencies obtained are high.

	30 hours Low Power.		30 hours Maximum continuous.		8 hours Full Power.	
	I.H.P.	Coal per I.H.P. lbs. per hour.	I.H.P.	Coal per I.H.P. lbs. per hour.	I.H.P.	Coal per I.H.P. lbs per hour.
Challenger	2·636	1·75	8·972	1·74	12·781	1·78
Hermes . . .	...	...	7·824	1·54	10·451	1·53
Cornwall	4·800	1·71	16·487	1·69	22·699	1·94
Dominion	3·889	1·93	12·843	1·68	18·438	1·77
King Edward VII. (part installation only) .	3·759	1·74	...	...	7·510	1·67
Commonwealth . .	3·644	1·73	12·769	1·68	18·538	1·83
Hindustan . . .	3·718	1·94	12·926	1·76	18·521	1·8

It may be of interest to note here that the later boilers have been fitted to use oil fuel in the English Navy, and the trials which have been made, burning oil or coal or both together, have given very satisfactory results.

In the American Navy, where this type of boiler has been very largely used, the first installations of Babcock and Wilcox boilers were in the gunboats *Marietta* and *Annapolis* of 1,300 H.P. The results proved so satisfactory that the American Navy Department has practically adopted this type of boiler as the standard for the American Navy.

It will be remembered that the gunboat *Marietta* accompanied the battleship *Oregon* from San Francisco to Cuba, during the Spanish-American war, and although the boilers had to be considerably forced to enable the ship to keep pace with the *Oregon*, it is stated that all that was required

at the end of a 13,000-mile run was a few fire-bricks, the boilers being otherwise in excellent condition and ready for further service.

The next vessel in the American Navy was the protected cruiser *Chicago*. She was refitted in 1897 with six Babcock and Wilcox boilers and four cylindrical boilers. Following on this the protected cruiser *Atlanta* of 3,000 H.P. was fitted with four water-tube and two cylindrical boilers. These are the only two vessels in which a combination with cylindrical boilers has been fitted in the American Navy; in most of the later ships this type of boiler alone has been fitted, amounting in all to over forty different vessels, but too numerous to cite in detail here.

In the case of the *Cincinnati* a careful series of tests was made on one of the eight boilers, the main particulars of which are given on table attached:—

TESTS OF BOILER FOR CRUISER *CINCINNATI.*

Steam pressure by gauge . . lbs.	209·3	207·4	213·6	210·8
Force of draught in ashpit—inches of water	·25	1·37	1·75	1·685
Escaping gases from boiler, . deg. Fahr.	466	570·6	640·0	Less than 900° Fahr.
FUEL PER HOUR				
Coal consumed per hour per sq. ft. G.S lbs.	20·45	35·61	50·95	59·75
Coal per hour per sq. ft. H.S. . . lbs.	·490	·853	1·004	1·432
Per cent. of moisture in steam . . .	0	0	·25	0
Equivalent evaporation from and at 212° Fahr. per sq. ft. H.S. . . . lbs.	5·18	8·75	10·07	13·67
Equivalent evaporation from and at 212° per lb. of coal . . . . lbs.	11·03	10·41	10·14	9·63

It will be seen that at a rate of combustion of 59.23 lbs. of coal per sq. ft. of grate surface per hour, 9.63 lbs. of water from and at 212° was obtained per lb. of coal. The rate of evaporation per sq. ft. of heating surface was 13.67.

The Babcock & Wilcox boiler is of the sectional type, the tubes being connected at each end into vertical sinuous headers. The circulation of the water is downwards from

the steam drum through the sinuous headers at the front of the boiler, then up through tubes which are inclined at an angle of 15° to the horizontal, and so through the back headers to the steam drum again.

The type of header used in the navy is square in section and sinuous in form, and is so arranged that each group of four tubes is accessible from a single door. In the mercantile type of boiler, now frequently used for land work, the tubes are $3\frac{1}{4}$ ins. diameter, with oval hand-hole fittings opposite each tube, although in many cases the naval type is preferred even for land work.

The boiler is constructed throughout of forged steel, and there is an entire absence of stays. The design is so arranged that the tubes in the side headers protect the casings, thereby adding considerably to their durability.

The products of combustion pass amongst the tubes and are distributed by baffling, which is usually of the type shown in Fig. 157, though modifications are sometimes used.

A few of the main features of this type of boiler may be briefly summed up as follows:—

The construction throughout is simple in character. The tubes are straight, and the joints are made by merely expanding and not by screwing—thus facilitating replacement, inspection, and repairs. The circulation is simple. The grate area bears a large proportion to the floor space occupied.

122. *Seaton Boiler* (*First type*).—The early type of the Seaton boiler (Fig. 158) is in many respects very similar to the D'Allest, the principal differences being the following.

The tubes are divided into large elements, each containing four or five vertical rows of slightly inclined tubes, connecting two flat water-spaces, and surmounted by a

cylindrical drum, thus forming a sort of narrow D'Allest boiler. Surmounting the whole is a transverse cylindrical

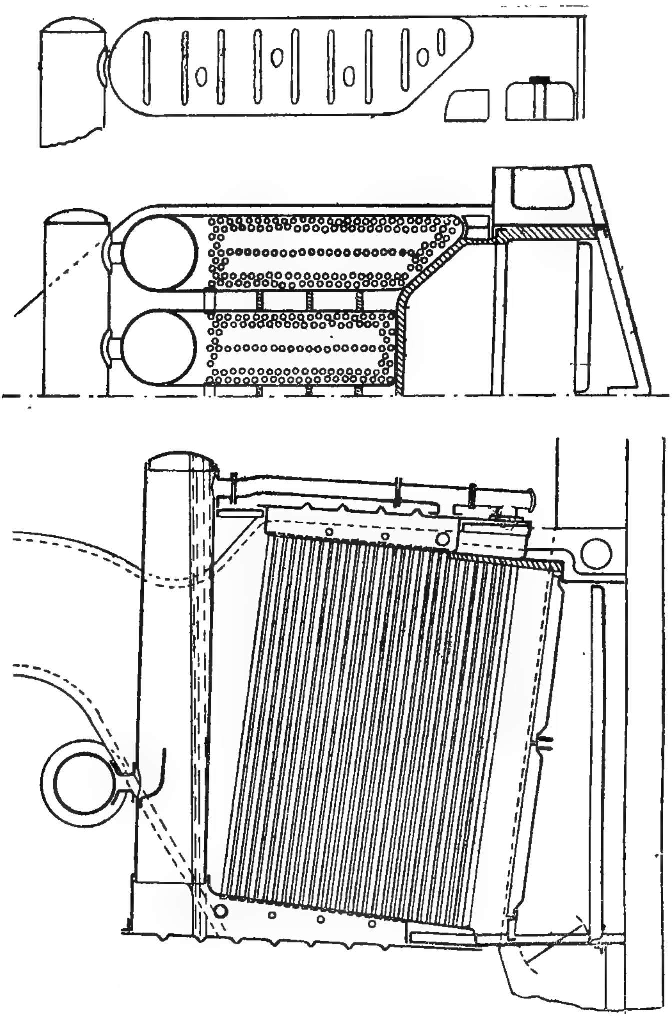


Fig. 158B.

Fig. 158A.

Fig. 158.

SEATON BOILER (FIRST TYPE).

collector connecting the different drums and serving as a common steam-chamber.

The narrowness of the water-spaces obviated the use of

the stays. The outside plates are stiffened by corrugations and are removable, thus dispensing with hand-holes opposite each tube.

The common steam-chamber has the disadvantage of materially increasing the height of the boiler.

123. *Anderson and Lyall Boiler.* — The Anderson and Lyall boiler (Fig. 159) is partly tubulous and partly

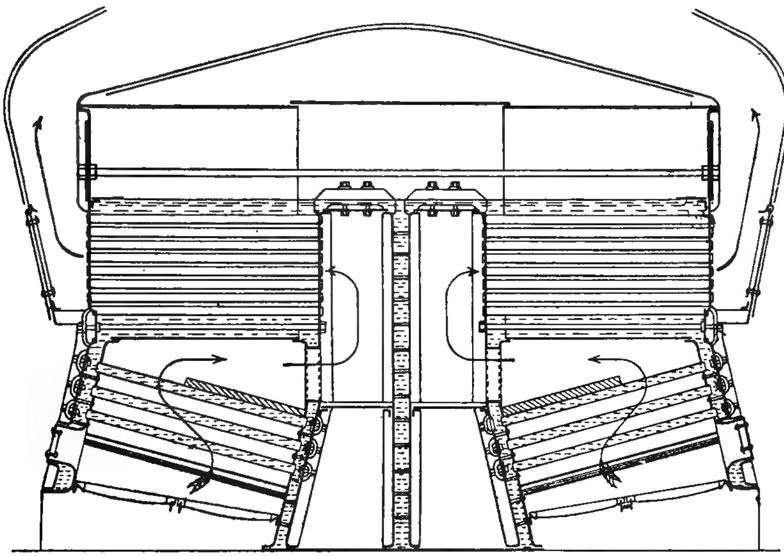


Fig. 159.

tubular. It is, in fact, composed of two distinct portions.

The lower portion is a kind of Joessel boiler with tubes set very wide apart, so that the flames pass over them without being unduly cooled, and their combustion is, therefore, not impeded. The upper portion is a complete cylindrical tubular boiler of a type long used on French pinnaces under the name of the "Bigot" boiler; in this portion the hot gases are further deprived of their heat.

Flat vertical water-spaces connect the two portions. Fig. 159 represents a double-ended boiler of this type.

Mr Stromeyer made some trials of this boiler, and believed its thermal efficiency to be higher than that of any other type of tubulous boiler. He calculated that 13,810 B.T.U. are utilised per pound of coal, having a calorific value of 17,170 B.T.U., which corresponds to an efficiency of 80.5 per cent. The weight of the Anderson and Lyall boiler is its greatest disadvantage; it amounts to 0.58 ton, water included, per square foot of grate area, and is about the same as that of locomotive type boilers.

The height of the boiler is also very great, even exceeding that of the Seaton boiler.

Attempts have been made by others to construct a combined water-tube and fire-tube boiler mainly with a view to its advantages for large units.

Mention may be made of the boiler designed at Creuzot in 1896, which possessed many promising features. The furnace was contained in a kind of Normand boiler having accelerated circulation; on leaving the furnace the gases traverse the tubes of a cylindrical boiler. Each of the two parts has its own distinct steam-chamber so as to facilitate the disengagement of the steam. This construction is adapted to withstand the highest rates of combustion. Trials were made burning from 20 to 62 lbs. of coal per square foot of grate surface per hour, the best results being obtained when consuming from 30 to 40 lbs.

The weight of the Creuzot boiler amounted to 0.732 tons per square foot of grate surface. A large floor space is occupied, the two parts of the boiler adjoining one another in a horizontal plane, instead of being vertically one over the other, as in the Anderson and Lyall boiler.

124. *De Dion-Bouton-Trépardoux, Ward, and Climax Boilers.*—As the water-spaces or headers have to support the

full boiler pressure, it would obviously be better to give them a cylindrical form. This has been done in the De Dion-Bouton-Trépardoux boiler, which has been fitted in several torpedo-boats of the French Navy.

It is of a vertical cylindrical form, and consists of a centra- cylindrical reservoir connected by radiating tubes to an outer annular water-space (Fig. 160).

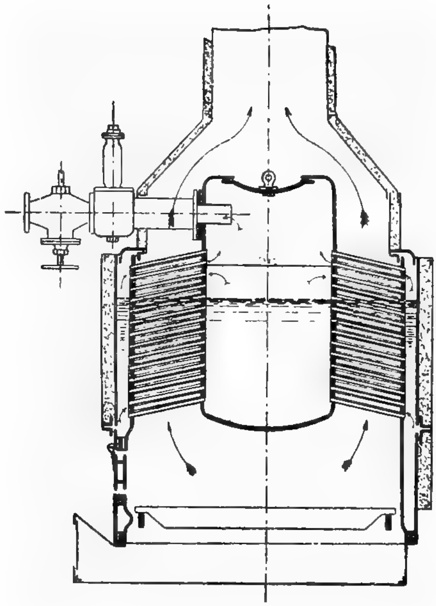


Fig. 160.

The direction of circulation through the tubes is from the outside water-space to the central reservoir; the upper tubes contain only steâm.

From the outset the De Dion boiler has given economical results, but there are now no examples in the French Navy, as it proved unequal to the forcing necessary on torpedo craft. It is, however, largely used for motor-cars, for which service it was, in fact, specially designed.

The Ward boiler (Fig. 161), the first of the water-tube type to be introduced into the United States Navy by the late Admiral Melville, late Engineer-in-Chief, is similar in some respects to the De Dion boiler, although more complicated.

The Ward boiler, as fitted on the U.S. coast defence vessel *Monterey* (in conjunction with cylindrical boilers) is a coil boiler, and consists of a central vertical drum surrounded by concentric coils or sections, A. Each section has a number of complete half circles of tubes placed one above the other.

The tubes of each section are connected in half circles by screwed joints to two vertical headers, BB, diametrically opposite to each other. The tubes, A, are about 2 ins. in diameter, and are set at an angle of about 10° with the horizontal to give direction to the current of circulation in them.

The central vertical drum receives the feed-water from an internal pipe that passes through its lower portion and extends to near the water-line. The space above the water-line in the central drum forms practically all the steam-space.

The headers, B, carrying the lower ends of the tubes, A, have a common connection at their bottom ends through pipes, B, with a water collector, C. This collector communicates with the central drum, and supplies the headers, B, with water. The upper ends of the headers are closed.

The headers carrying the highest ends of the half circles connect with a horizontal receiver, D, at their upper ends, through which all steam generated passes into the top portion of the central drum. At their lower ends they connect with a bottom collector, G, which serves as a mud-drum. The headers proper do not extend below the level of the generating tubes, the connections with the lower water collectors, G and C, being made through iron pipes, B, of about $3\frac{1}{2}$ ins. diameter, screwed into the bottom ends of the headers, and joined to the water collectors by shallow stuffing-boxes. The bottom collectors are below the grate, and they and the headers are of cast steel. The grate is circular, and composed of segments placed around the central vertical reservoir. The central reservoir is divided into two parts by a horizontal partition; the feed-water finds its way down to the horizontal collector, C, and the steam issuing from the generating tubes is received at the upper end of the central reservoir.

All the joints are very simple, and the entire boiler should have great elasticity, owing to the curvature of the generating

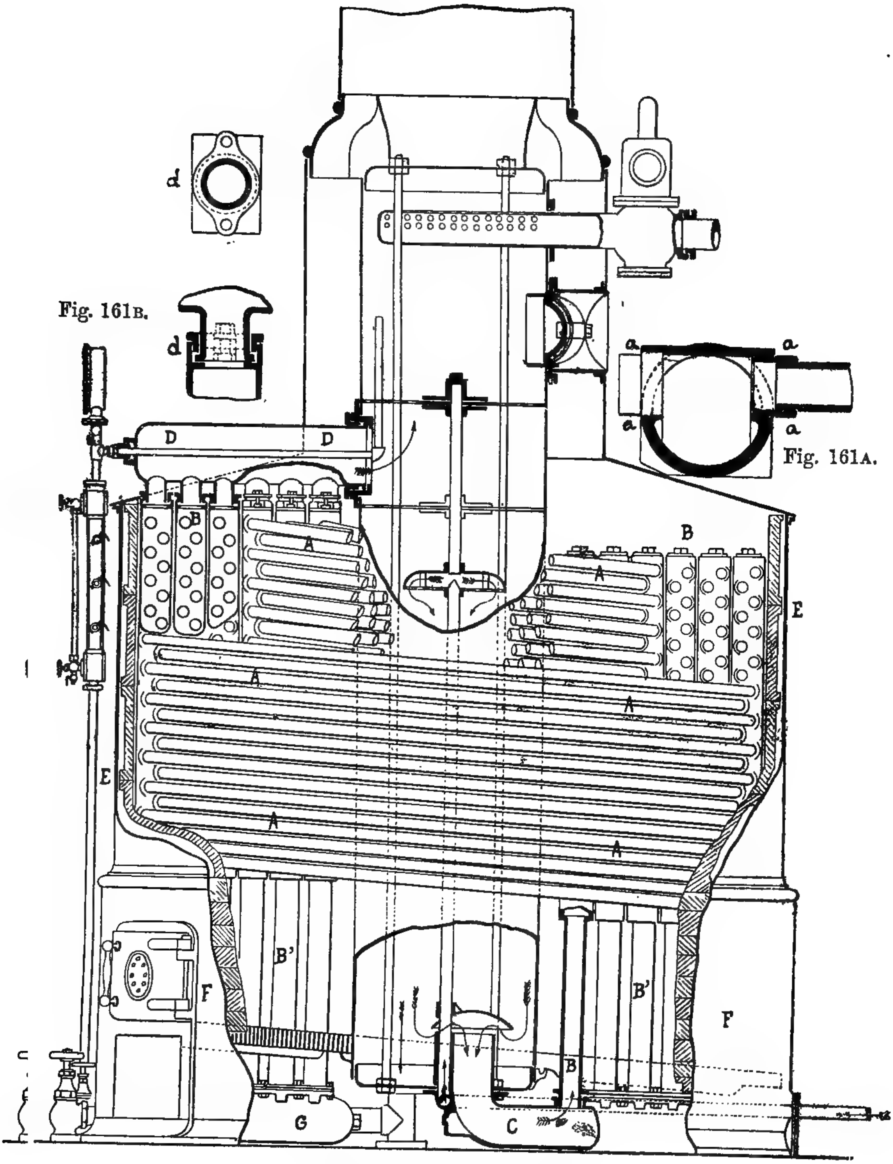


Fig. 161. WARD BOILER.

NOTE.—The boilers of the *Monterey* are of this type, but larger, having 18 concentric rows of tubes instead of 12.

AA. Coils of tubes connected to the vertical headers BB, by screwed ferrules *aa*.

BB. Vertical headers connected at their lower ends to tubes of smaller area B'B', among which the gases circulate.

aa. (Fig. 161A). Ferrules forming the connection between the tubes A and the headers B.

CC. Bottom horizontal collectors, to which the tubes B'B' are connected by fixed joints.

DD. Upper horizontal collector, to which the vertical headers BB are connected by expansion joints.

dd. (Fig. 161B). Expansion joints; stuffing-boxes packed with asbestos connecting the collector D with the headers BB. The gland bolts have flat T-heads lodged in the thickness of the lugs formed on the box.

EE. Casing of plate, 0·1 in. thick, lined with hollow bricks $1\frac{3}{4}$ ins. thick.

FF. Casing of plate, 0·118 in. thick, lined with hollow bricks $4\frac{1}{4}$ ins. thick.

GG. Settling drum.

tubes. Its principal disadvantage is the circular form of the grate, which renders the stoking difficult, especially at the sides, and necessitates clear room for stoking all round the boiler.

The Ward boiler is one of the lightest in existence; the two boilers of the *Monterey*, with a total of 73.74 sq. ft. of grate surface, weigh 15.08 tons without water and 17.5 tons with water, which makes only 532 lbs. or 0.230 tons per square foot of grate. This type of boiler has been fitted on four of the U.S. revenue cutters.

The following are some particulars of a Ward coil boiler (other than the *Monterey*) tested under forced draught:—*

Heating Surface	sq. ft.	2,473·5
Grate Surface	,,	53
Ratio $\frac{\text{H. S.}}{\text{G. S.}}$		46·67
Weight of boiler, empty	tons	11·84
,, ,, water	,,	2·01
,, ,, boiler and water	,,	13·85
,, ,, ,, per sq. ft. of grate	lbs.	585·3
,, ,, ,, ,, ,, H. S.	,,	12·5
Evaporation from and at 212° Fahr.	,,	7·31
Coal per square foot of grate	,,	55·05

In the trials of the *Monterey* the Ward boilers under the same conditions of draught as the return-tube cylindrical boilers worked most satisfactorily. When forcing the boilers the rate of combustion was limited, not as in cylindrical boilers by the liability of starting the tube joints, but simply by the fear of melting the grate which was of cast iron.

As the result of experience gained with the *Monterey*, Admiral Melville reported in favour of water-tube boilers, which were at first partially adopted and afterwards generally fitted into the ships of the United State's Navy. However, in place of the Ward boiler, types better suited to naval requirements, principally the Babcock & Wilcox and the

* *Journal of the American Society of Naval Engineers*, vol. ii., No. 4.

Niclausse, have been adopted. Mr Ward has recently constructed boilers of a more simple form, cylindrical or rectangular in shape, and these have been largely used on launches, etc., but fall under the heading of boilers with accelerated circulation.

CLIMAX BOILER.

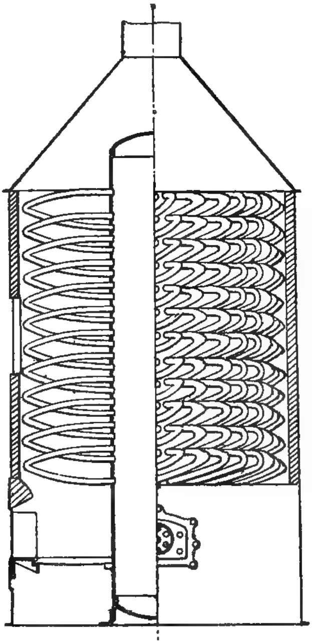


Fig. 162.

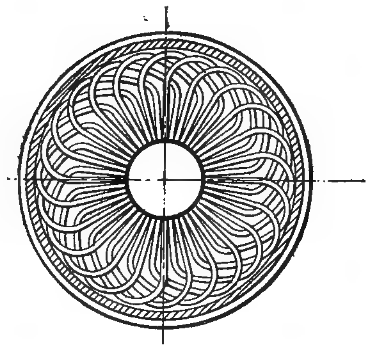


Fig 162A.

The external cylindrical form is as well adapted to the single water-space system as the rectangular form. Although this system is dealt with in paragraph 126, Mr Morin's Climax boiler may here be mentioned as an instance of the cylindrical single water-space construction.

The Climax boiler represented by Figs. 162 and 162A consists of a central vertical cylindrical reservoir, around which the fire-grate is arranged as in the Ward boiler. The generating tubes are all bent to exactly the same shape, the two ends being expanded into the reservoir at different levels, the water entering at the lower and the steam escaping by the upper end.

The Climax boiler does not appear to have ever been employed on board ship, but numerous land installations exist. It was shown at the Paris Exhibition of 1900 and

described by M. Bellens and M. Boutte in *La Mechanique à l'Exposition* and in the *Revue Technique de l'Exposition.*

125. *Towne Boiler.*—The Towne boiler, which has been fitted to launches and gun-boats in America, has narrow water-spaces at each side with a bend at the centre of their height. The tubes connect the lower portion of one water-

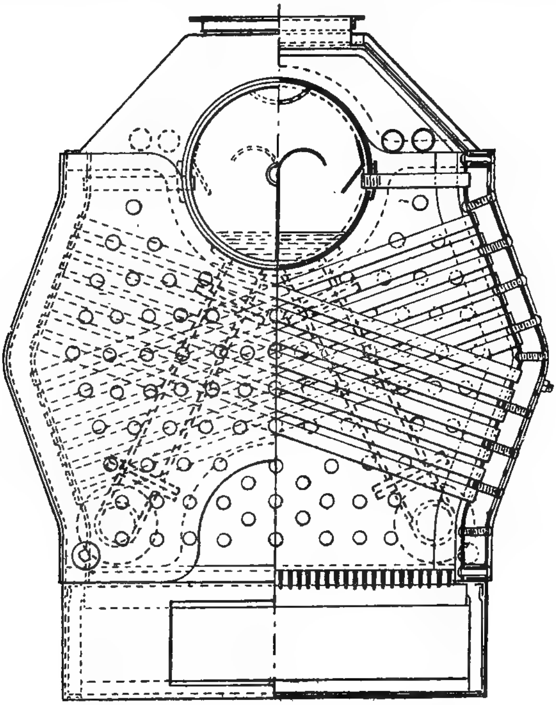


Fig. 163.

space to the upper portion of the other, the two sets of tubes crossing one another at the centre (Fig. 163).

This novel arrangement permits an inclination to be given to the tubes favourable to a rapid circulation, and by increasing the height of the furnace, is conducive to good combustion.

The Towne boiler is provided with downtakes for the return of the water, and therefore possesses some of the advantages of boilers with accelerated circulation, although its general construction more nearly resembles that of boilers with free circulation.

As regards circulation the Towne boiler may be classed with those described in the following paragraph, on account of the symmetry of the two water-spaces, each one of which serves the double purpose of supplying the tubes with water and receiving the steam generated in them ; its circulation, however, more closely resembles that in boilers with two water-spaces.

126. *Water-tube Boilers with a Single Flat Water-space.—The Lencauchez Boiler.—Marshall-Thornycroft and Petit-Godard Boilers.*—Instead of allowing the circulation to depend on uncertain and variable differences of pressure between two water-spaces, or headers, it may be produced simply by the disturbing forces in the tubes themselves due to the generation of steam. A boiler constructed on this principle would have only one vertical water-space, or row of headers, to which both ends of the generating tubes are connected at different levels. The water enters at the lower, and the mixture of steam and water is discharged from the upper end.

This system was contemplated a long time ago by a well-known engineer, M. Lencauchez, who submitted very complete designs to the French naval authorities—in which, by the way, were incorporated a very interesting arrangement of jets over the furnace. We will do no more than mention the Lencauchez boiler, as it has not yet been tried at sea, at least in ships of war; in principle it is exactly similar to the one we are about to describe.

The boiler represented by Fig. 164 is due to the joint efforts of Mr Marshall of Newcastle and Sir John I. Thornycroft; in its construction the simplicity of a free

circulation from one level to another in a single water-space is realised.

The Marshall-Thornycroft boiler is only intended for moderate rates of firing with natural draught, or for very

MARSHALL-THORNYCROFT BOILER.

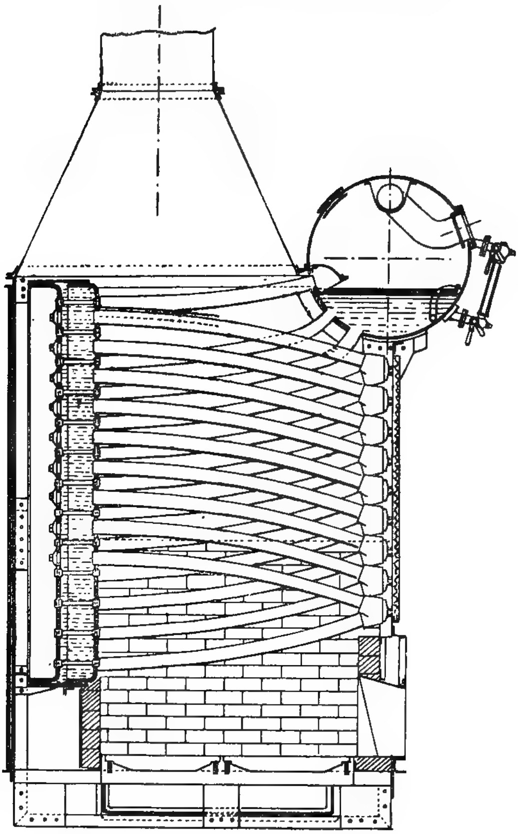


Fig. 164.

slight forcing. Results of tests afloat are not yet available. M. Lencauchez anticipated an evaporation of 8 lbs. of water per pound of coal with good natural draught on his boiler.

In the Petit-Godard boiler (Fig. 165) the circulation is

more rapid than in those previously described, on account of the great difference in level of the two ends of the generating tubes; it was designed to withstand high rates of forcing. The furnace, lined with fire-brick, is in front

PETIT-GODARD BOILER.

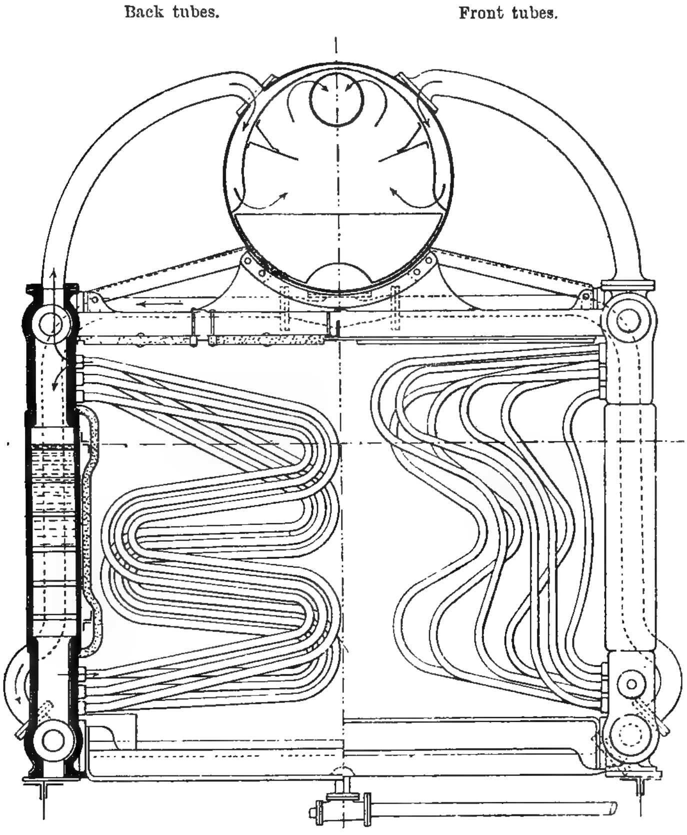


Fig. 165.

of the boiler proper; when under forced draught the furnace casing becomes so hot that the work of stoking is rendered extremely arduous.

As the result of somewhat inconclusive trials with the Petit-Godard boilers fitted on board torpedo-boat No. 73 and the

Bouet-Willaumez it has been decided to abandon the use of this type of boiler in the French Navy. It has, however, been retained on the *Bouet-Willaumez* for experiments with liquid fuel. For torpedo-boats it cannot successfully compete with boilers having accelerated circulation.

Referring to Fig. 165, it is hardly necessary to remark that although the Petit-Godard boiler has two flat water-spaces, yet it belongs to the same type as these having only one; in fact, as far as the circulation is concerned, it consists of two separate and distinct units so combined as to form one boiler.

The Leblond and Caville boiler (Fig. 166) may be mentioned as being analogous to the Petit-Godard. It is cylindrical, with an internal furnace, and is, in other respects, an offshoot of the Galloway boiler. It is another example of the fact that the mere possession of water tubes does not entitle a boiler to be classed as a water-tube boiler.

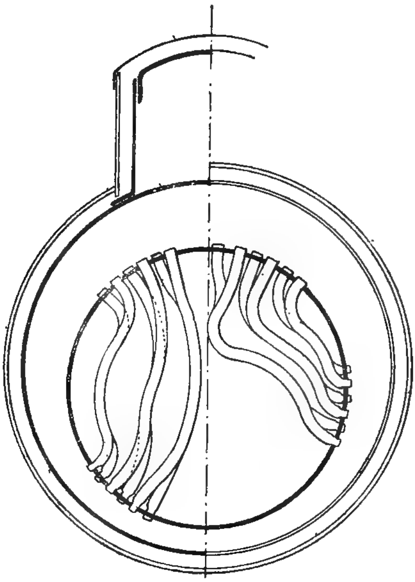


Fig. 166.

127. *Grille - Solignac Boiler.*—Messrs Grille & Solignac have collaborated in the production of various designs of boilers, retaining all the restricted openings at the bottom ends of the tubes characteristic of the original Solignac boiler. Previous to last year the arrangement adopted was somewhat similar to that of the Lencauchez boiler, *i.e.*, with only one water-space or row of headers. At the present time

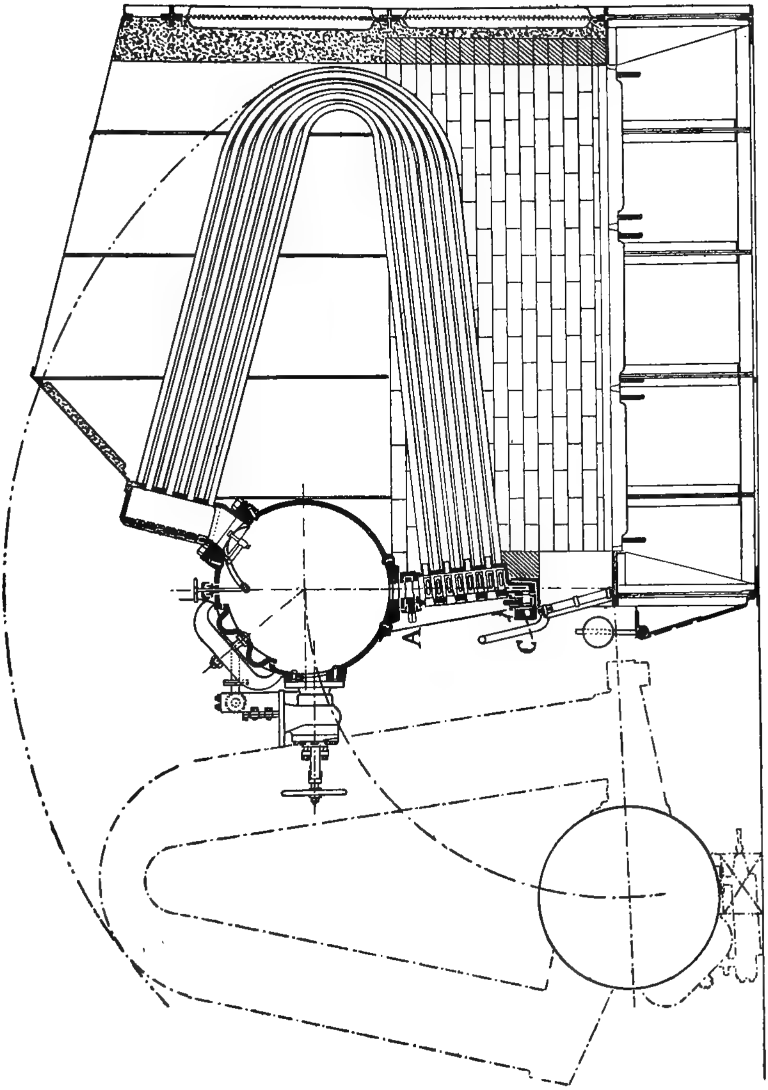


Fig. 167.

the water-space or headers are in two parts—the lower one distributing the water to the tubes and the upper one collecting the steam—this unique arrangement places the boiler in a class apart. The great difference in level between the two ends of each tube would almost justify the inclusion of the Grille-Solignac boiler amongst those having accelerated circulation. It is claimed that it is capable of evaporating more than 14.4 lbs. of water per square foot of heating surface.

Only one installation of this boiler has yet been made afloat—on a tug on the Seine, and it is included here more on account of the originality of its design than because of its use on board ship.

The generating tubes are arranged in groups of four, six, or eight rows. Each group is provided with a cock and valve at its inlet from, and its outlet to, the steam and water drum for the purpose of isolating the group from the rest of the boiler at will; a blow-off is fitted at C. By closing the cock A at the inlet to the group, and opening the blow-off cock C any group can be completely blown through, and the tubes entirely emptied of water, thus maintaining them in a perfect state of cleanliness. A damaged tube can be plugged without interrupting the working of the boiler by first isolating the group containing it. The valve at the outlet closes automatically should a tube give way—thus resembling the Ravier valve described later in paragraph 166. It also gives visible indication of the mishap while preventing the discharge of steam from the drum.

The whole of the parts under pressure are supported in gudgeons at each side towards the front of the boiler, and can in their entirety be swung forwards through an angle of about 90°, in which position they are exposed and readily accessible for external examination, cleaning, or repairing.

128. *Field Boiler.*—Before considering the somewhat numerous group of boilers with free circulation and with only

one water-space, consisting of the Collet and its derivations, which to-day are in strong competition with those having two independent water-spaces or rows of headers, it is convenient to refer here to the Field boiler, which may be looked upon as their prototype.

In the Field, or rather the Perkins boiler, as modified by Field, the tubes are verticle, and hang from a horizontal tube-

FIELD BOILER.

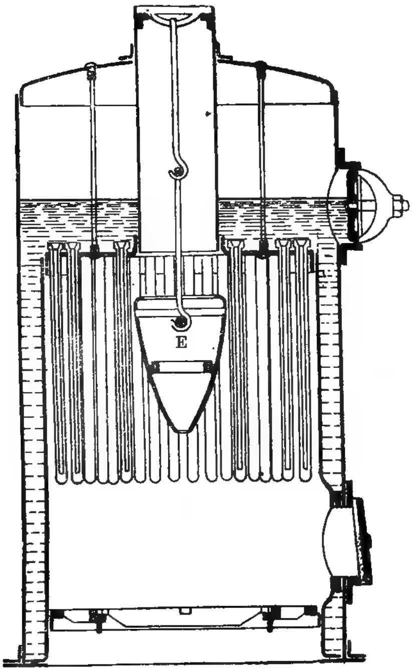


Fig. 168.

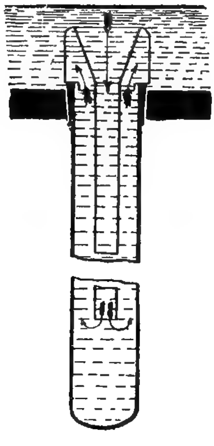


Fig. 169.

plate, the circulation being provided for by means of an internal tube. The direction of the current is downwards through the internal tube and upwards through the annular space between the two tubes. These descending and ascending currents in the one tube recall the well-known experiment of the cylindrical vessel heated from below in which the

circulation is improved, and the disengagement of steam facilitated by the introduction of a concentric screen, also cylindrical, which separated the confused currents into two of opposite character. The Field boiler was first employed on board ship as a donkey boiler at a time when its only competitor for rapid steam raising was the Belleville.

The vertical tubes of the Perkins boiler, hanging from a single reservoir, are irrational in principle, because the current leaving the outer annular space impedes the flow of water to the central inner tube. This defect was partly overcome by Field, who fitted a conical mouthpiece to the top of the internal tube (see Fig. 169). However, the circulation is still imperfect, and at low rates of working the tubes are liable to become choked with scale or deposits.

129. *Collet Boiler.—Niclausse Boiler.*—The inlet and outlet currents which obstruct each other in the Field or Perkins

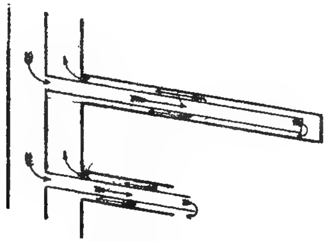


Fig. 170.

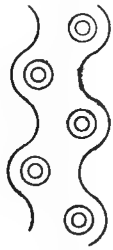


Fig. 170A.

tubes permit themselves to be easily directed when the tubes are placed horizontally, or nearly so, and the tube-plate vertical. This is especially the case if the water-space into which the tubes deliver is divided into two parts, and the internal tube is carried through the central division so that the outlet of the tubes is on one side of the division and the intake on the other.

This arrangement was patented in 1878 by Collet, and fitted on some boats, and subsequently on the despatch boat

Elan, where it rendered good service before being replaced by a Niclausse boiler. The headers are composed of a series of rectangular boxes of sinuous form somewhat similar to those of the Babcock & Wilcox boiler. Two vertical rows

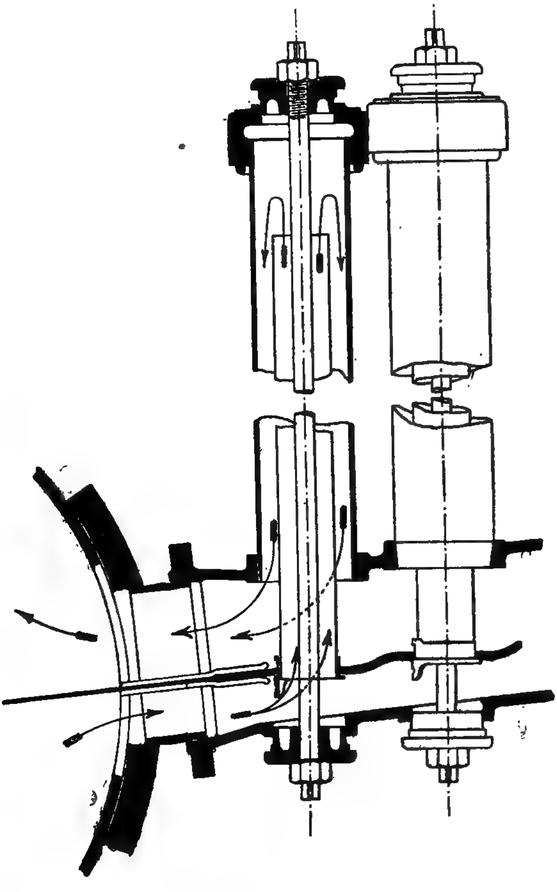


Fig. 171.

of tubes arranged in a zigzag formation are connected to each header. The outside tube is fitted into the inner plate of the header next to the fire by means of a conical joint; the inner tube terminates in the central diaphragm of the header. An internal stay screwed at either end holds the

whole in position (Fig. 171). Though the arrangement is a very secure one, it is not easily taken apart.

M. Niclausse introduced several improvements to Mr Collet's boiler, and especially in the manufacture which led to a rapid development of this boiler; Figs. 172 and 172A illustrate the first type supplied to the French Navy and fitted on the *Friant*. The diameter of the tubes was 3.23 ins., and their thickness was .128 in.

To increase the heating surface, M. Niclausse reduced the diameter and increased the number of the tubes. The early boilers with small tubes were fitted on torpedo-boats and on the *Téméraire* and are referred to in paragraph 130. The external tubes were 1.58 ins. diameter and the internal tube .75 in. and .1 and .02 in. thick respectively. The space between the outer and inner tubes available for steam and water was .31 in. During some shore trials when burning 82 lbs. per square foot of grate, an evaporation of 6.8 lbs. per pound of coal was reached.

In the boilers for larger class of vessels there are tubes of two different diameters. This type of boiler has been adopted on the *Yayéyama* and *Suffren*; Figs. 173 and 173A illustrate the boilers of this latter boat. Each section or header is fitted with six tubes of large diameter and above these thirty tubes of small diameter.

The external diameters of the tubes are 3.23 and 1.58 ins. and 1.58 and .75 ins. for the internal tubes respectively, the thicknesses being the same as that given above.

Latterly M. Niclausse has used tubes of uniform diameter of 3.23 and 1.58 ins. placed in two rows in the headers; he has also abandoned the use of the cast sinuous headers for the plane rectangular form which are more easily cleaned. The headers are now made out of a solid drawn tube of square section and the sides are slightly thickened where the tubes pass through, so as to provide for the necessary thickness and obliquity of the tubes, the whole operation being carried out by means of a powerful hydraulic press.

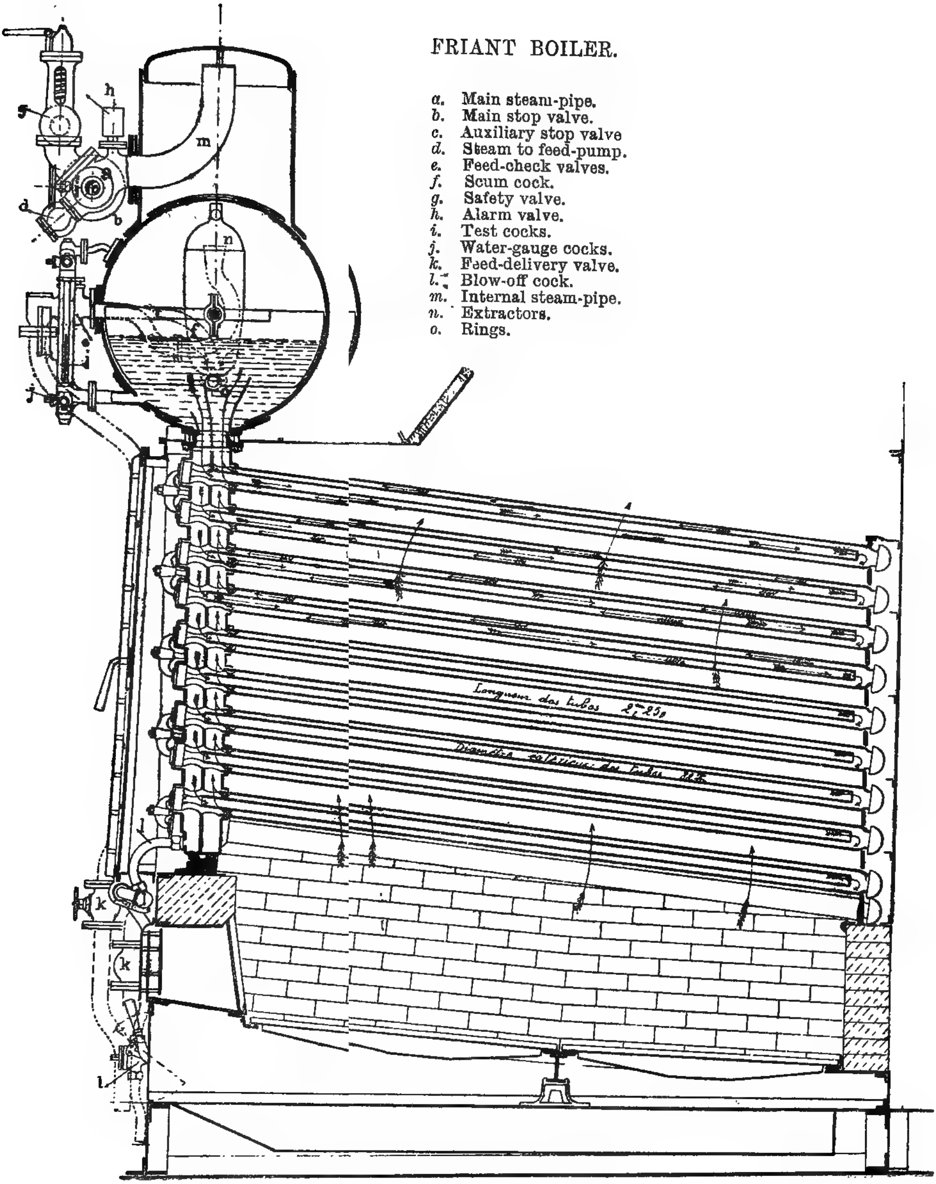

FRIANT BOILER.
a. Main steam-pipe.
b. Main stop valve.
c. Auxiliary stop valve
d. Steam to feed-pump.
e. Feed-check valves.
f. Scum cock.
g. Safety valve.
h. Alarm valve.
i. Test cocks.
j. Water-gauge cocks.
k. Feed-delivery valve.
l. Blow-off cock.
m. Internal steam-pipe.
n. Extractors.
o. Rings.

Fig. 172.

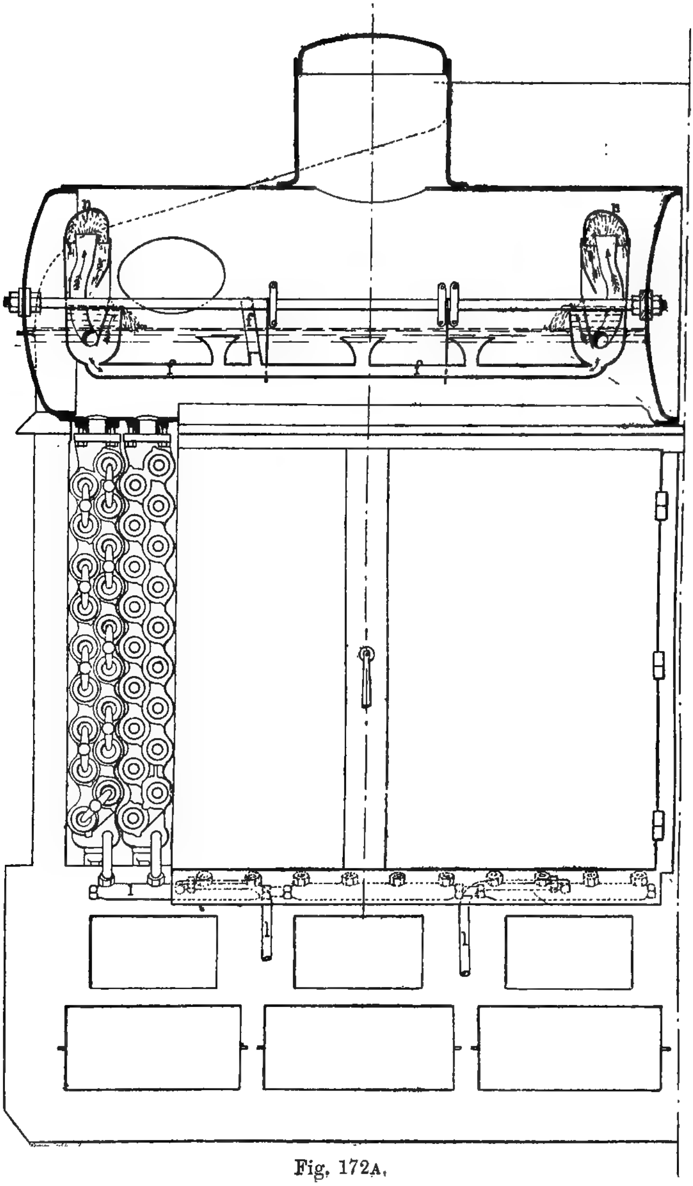


Fig. 172A.

BOILER OF THE *SUFFREN.*

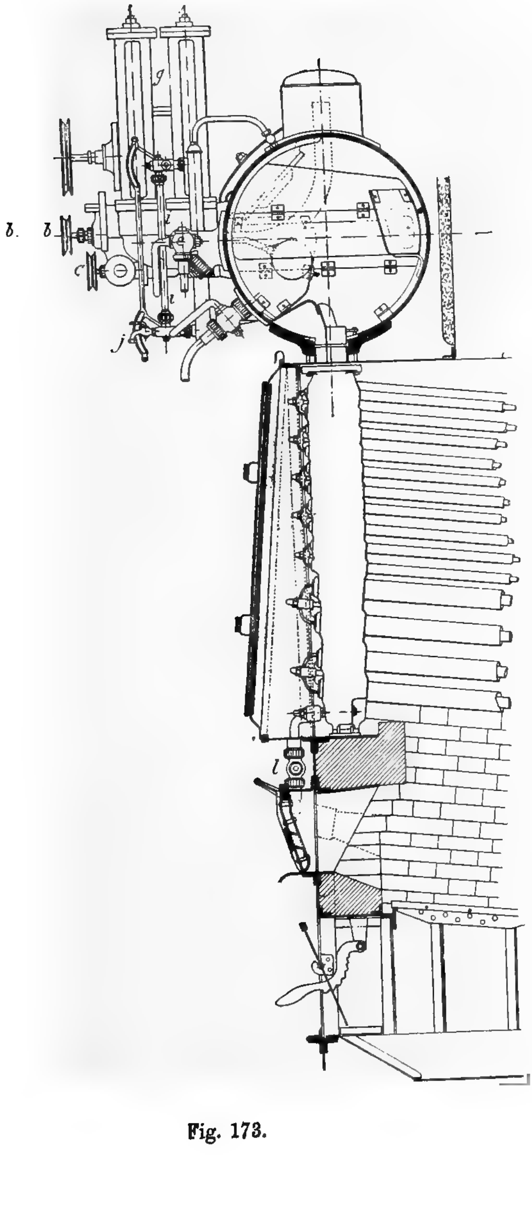


Fig. 173.

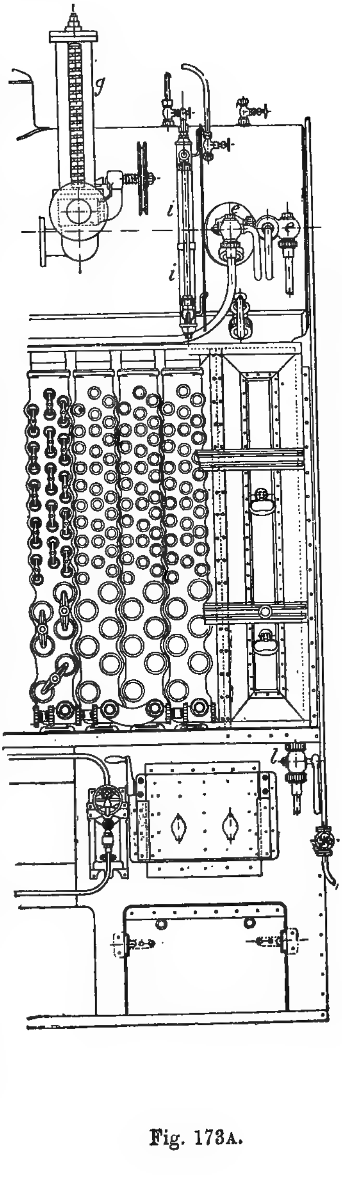
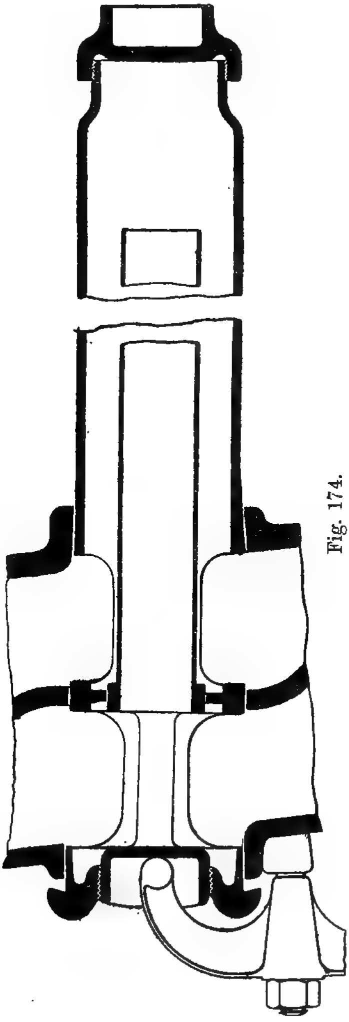


Fig. 173A.

From the very outset M. Niclausse used a form of joint which enabled the tubes to be taken down and replaced from the front of the boiler. The outside generating tube, which is put in first, fits into the back and front of the header by means of two long coned joints; the whole is held in position by means of a dog, which bears upon the centre portion of the lugs of two adjacent tubes. The attention that has been devoted to the details, coupled with the elasticity of the sides of the header, assures the tightness of the two coned joints.



DETAILS OF LANTERN.

Fig. 174.

The first arrangement used and that now in actual service is shown in Fig. 174.

The method of connecting the tubes to the headers is as follows:—

The external tube was, until quite recently, permanently connected at one end to a malleable iron casting, which is known as a "lantern," but the two are now made in one piece. The end of the tube where it joins the lantern is slightly thickened and turned to a slight taper, and fits into a tapered hole in the rear plate of the header. The middle portion of the lantern, which is cylindrical and of slightly larger diameter, fits into the dividing plate or diaphragm of

the header, and the extreme end, which is of larger diameter still, is coned, and fits a coned hole in the front plate of the header. This end is screwd internally for the reception of a screwed plug, forming the end of the lantern of the inner tube. Any pressure in the boiler only tends to press the coned surfaces more firmly on their coned seats in the sides of the header. The object of making each succeeding bearing surface of the lantern of larger diameter than the one before is to enable the lantern and tube to be drawn out from the front of the boiler. The central cylindrical bearing of the lantern is made an easy fit in the diaphragm dividing the header.

The inner circulating tube is also provided with a lantern of somewhat different form. The end to which the inner tube is attached has a bearing inside the central cylindrical portion of the lantern of the outer tube at the place where it passes through the diaphragm, and the other end, which is slightly coned and also larger, screws into the outer portion of the external lantern, completely closing it. The inner tube is supported by its lantern where it passes through the middle cylindrical portion, but as it is exposed to the same pressure internally and externally, it can be made extremely light; the support afforded in the header, provided it is not excessively long, is quite sufficient. The various cones and the holes in the header and diaphragm are concentric. The outer lantern is fitted with lugs or ears to enable it to be removed from the header. The tubes are kept in place by means of a dog, which bears upon the centre portions of the plugs of two adjacent tubes, and is held there by means of a stud and nut. The external tube is slightly reduced in diameter at its free end, and closed with a cap to facilitate cleaning. At this end it is supported loosely in a steel plate, but the whole tube is free to expand and contract, being only held rigidly at the front end, and consequently the boiler is entirely free from the troubles due to the expansion of

the tubes. The headers are secured to the top drum by a cone-connection somewhat similar to the method used in connecting the tubes and headers.

This ingenious arrangement ensures tightness of the joint when properly executed, besides providing facilities for removing and replacing the tubes. In service, however, the large lanterns proved to be rather fragile, especially when corroded; this gave rise to blowing out of the tubes and other consequent difficulties. This and other practical difficulties lead M. Niclausse to bring out his 1901 model, illustrated in Fig. 175. In the new arrangement the lantern has entirely

DETAILS OF THE TUBES OF NICLAUSSE BOILER (1901.)

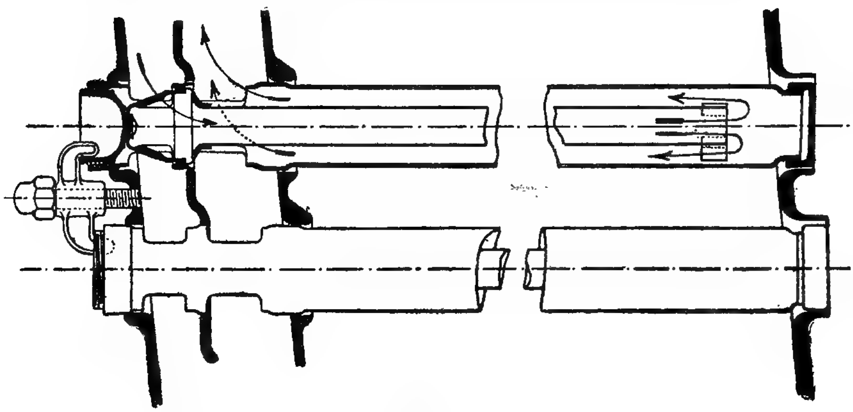


Fig. 175,

disappeared. The outer tube is expanded by special tools while hot so as to fit the central and back openings of the headers. The tube is jumped up at the front end in order to provide the necessary thickness for the coned joint outside and the screw joint inside. The internal tube terminates just short of the central diaphragm; a stamped ring fills up the annular space, and is attached to the piece closing the tube by means of two branches riveted to it. The internal tube is supported at the other end in order to maintain it central with the outside tube. The bottom end of the outside tube is

closed by a cap being screwed on to it, the fitting and taking apart is carried out separately on the two tubes, the tightness of the conical joints is obtained by means of a removable stirrup or dog, and that without any more difficulty than in the earlier form.

The top drum is sufficiently large to minimise any small irregularity which may occur in the feeding; baffles separate the currents of water and steam. A steam dome is fitted and the feed inlet is surrounded by a casing of thin plating which acts as a mud-drum. The various details are clearly shown in Figs. 172 and 173, where the same letters are used for similar parts. Special attention may be drawn to the headers where they receive the tubes, and to the upper drum where the junction of the headers is effected; the strengthening of the drum where the headers enter has to be specially provided for. The outside tubes are sometimes solid-drawn and sometimes brazed, and no accidents due to brazing have as yet occurred; the internal tubes which are not exposed to pressure are formed merely of light plate. The method of construction and the tools used therein have been most carefully designed and carried out.

130. *General Features of the Niclausse Boiler.—Results obtained.*—The introduction of the Niclausse boiler into the French Navy was largely due to the satisfactory trials of the *Friant.* It having been decided to abandon cylindrical boilers before settling which type to adopt, it was decided to try the Belleville, D'Allest, and Niclausse boilers on the three similar boats, the *Chasseloup-Laubat*, the *Bugeaud*, and the *Friant* respectively. The results obtained are given in paragraph 170.

The first trials of the *Friant* showed a low efficiency; dense smoke was given off from the funnel, and the uptakes and the base of the funnel became excessively hot, but the installation of more powerful fans overcame this difficulty.

Experience has shown that the fires should always be kept thin, and that the stoking should be methodical, as described in paragraph 46. This system of stoking is a curious return to an old method rendered compulsory in the French Navy in 1866, by the influence of Rear-Admiral Labrousse. Each fire is charged with about 30 lbs. of coal at intervals of two minutes. Under these conditions the results obtained on the *Friant* were as follows:—

1. *Coal-consumption Trials.*

Grate area	sq. ft.	78·25
Heating surface		2323·95
Ratio $\frac{H.S.}{G.S.}$		29·7
Boiler pressure	lbs. per sq. in.	180
Pressure at the reducing valves	,,	141·6
Number of expansions in the engines $\Delta = \frac{D^2}{id^2}$		12·40
Coal burnt per sq. ft. of grate	lbs.	10·25
,, ,, horse-power hour	,,	1·49

2. *Speed Trials.*

Boiler pressure	lbs. per sq. in.	194·57
Pressure at the reducing valves	,,	163·14
Number of expansions in the engines $\Delta = \frac{D^2}{id^2}$		7·63
Coal burnt per sq. ft. of grate	lbs.	25·03
,, ,, horse-power hour	,,	2·032

The results attained encouraged further applications and the Niclausse boiler was fitted on board the *Henry IV.*, and then on board a large number of boats of larger tonnage; the cruisers *Kléber*, *Condé*, *Gloire*, *Léon Gambetta*, *Jean-Bart*, *Isly*, *Ernest-Renan* and the battleships *Suffren*, *République*, and *Justice*. This type even rivals the Belleville boiler in the extent to which it has been applied. It has been fitted in other countries besides France, namely in Russia, in the United States, in Italy, in England, in Japan, and in the Argentine Republic. Notably on the *Retsivan*, *Variag*, *Khrabry*, the new *Maine*, *Connecticut*, *Colorado*, *Pennsylvania*, *Virginia*, *Georgia*, *Regina-Margherita*, *Garibaldi*, *Francisco-Ferruccio*, *Pelayo*,

Cristobal-Colon, *Freya*, *Gazelle*, *Yayéyama*, *Katori*, *Kashima*, and the *Presidente-Sarmiento*. In the British Navy it was fitted first on to the first-class gun-boat *Seagull*, and subsequently on the *Berwick*, *Suffolk*, *Devonshire*, and *Carnarvon*, cruisers of 22,000 horse-power; also on the *New Zealand* (18,000 I.H.P.), and on the sloops *Fantome*, *Cadmus*, and *Clio*.

Various evaporative trials have been made which show that the Niclausse boiler is economical at all ordinary rates of working, and can be pushed without danger to up to 35 lbs. per square foot of grate.

The following results were obtained by Messrs Humphrys and Tennant on a shop boiler with ordinary Cardiff coal:—

Grate area	19·16 sq. ft.
Heating surface	630 ,,
Ratio $\frac{H.S.}{G.S.}$	32·9

Duration of trial	8 hours.	8 hours.	8 hours.	8 hours.	4 hours.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Coal burnt per sq. ft. of grate per hour	12·94	18·96	25·31	29·2	35
Water evaporated. Actual	9·28	9·25	8·66	8·27	7·93
Water evaporated. From and at 212°	11·2	11·06	10·45	9·90	9·59

Professors Kennedy and Unwin made some careful tests at Thames Ditton with the following results:—

Grate area	17·98 sq. ft.
Heating surface	649·00 ,,
Ratio $\frac{H.S.}{G.S.}$	36·1

Duration of trial	7·67 hrs.	7·45 hrs.	2·95 hrs.
Lbs. of coal per sq. ft. grate per hr.	13·3	13·45	25·67
Efficiency of boiler per cent.	73·1	72·1	73·1

The following are the results of a series of experiments

made by Mr Jay Witham, in the workshops of Messrs Cramp of Philadelphia. The coal used had a rather lower calorific value than that employed in the preceding tests, varying from 13,140 to 13,940 B.T.U.

Grate area	28 sq. ft.
Heating surface	1,092 ,,
Ratio $\frac{H.S.}{G.S.}$	39

Duration of trial	10 hours.	10 hours.	10 hours.	10 hours.
	Lbs.	Lbs.	Lbs.	Lbs.
Coal burnt per sq. ft. of grate per hour	13·7	13·6	12·8	21·9
Water evaporated. Actual	8·3	9·2	8·57	9·04
Water evaporated. From and at 212°	9·98	10·6	10·03	10·85
Thermal efficiency per cent.	74·3	78·7	76·5	77·5

The above figures were surpassed in tests made on three boilers of the *Yayéyama*, made in M. Niclausse's works by Commander Yamada.

Grate area	133·7 sq. ft.
Heating surface	4065·54 ,,
Ratio $\frac{H.S.}{G.S.}$	30·4

Duration of trial	2 hours.
	Lbs.
Coal burnt per sq. ft. of grate per hour	14·3
Water evaporated: Actual	9·59
Water evaporated: From and at 212°	11·6
Temperature of smoke	482° Fahr.

To these figures may be added those given by a boiler, destined for the *Davout*, where 8.9 lbs. and 8.2 lbs. of water were evaporated per pound of coal (without any correction for temperature) when burning 19 and 33 lbs.

per square foot of grate. It will be seen that from the point of view of thermal efficiency, the Niclausse boiler more than holds its own amongst boilers with free circulation.

It permits of an evaporation of 8 to 9 lbs. of water when burning 33 lbs. per square foot of grate.

M. Niclausse attempted to bring out a boiler suitable for torpedo-boat work. He reduced the diameter of the tubes to 1.58 ins., and made the ratio of G.S. to H.S., 1 to 50. Such a boiler during a shop trial evaporated 6.77 lbs. of water per pound of coal when burning 82 lbs. per square foot of grate.

A similar boiler was fitted on the torpedo-boat *Téméraire* in 1899. The furnace was only 26 ins. high and the gases consequently escaped unburnt with a high funnel temperature.

The results obtained from the *Téméraire* in service clearly indicated that the boilers with small tubes were not suitable for torpedo-boat work.

M. Niclausse then brought out a new design with a higher combustion-chamber and tubes of 2.37 ins. instead of 1.58 ins., and the evaporation, from and at 212° Fahr., rose to 11.6 lbs. when burning 18.4 lbs. per square foot, and 8.8 lbs. when burning 71.7 lbs. per square foot of grate.

The gun-boats *Zélée* was fitted with the same class of boiler as the *Téméraire*, having 1.58-in. tubes. The results were in the first instance somewhat unsatisfactory, but since 1901 only one slight accident has occurred, due, it is stated, to an excessive use of lime.

The *Fleurus*, (4,000 I.H.P.) also has 1.58-in. tubes, but the results in this instance have been more satisfactory. Instances of broken lanterns have occurred especially if worn or corroded, and more particularly with the 1.58-in. tubes. The risk of broken lanterns is not so great with

3.23-in. tubes as with the smaller tubes, but the improvements referred to in paragraph 129 have practically overcome this difficulty.

In general Niclausse boilers afford unrivalled facilities for inspection and upkeep. It is not sufficient merely to empty the tubes from the front ends, they must be taken out and completely emptied unless the whole boiler when laid by is filled up with fresh water and lime. Frequent inspections are necessary to see that no deposits are occurring to stop the circulation. The taking down and replacing of the tubes must be done with care so as not to injure the fine threads. The brickwork in the front of the boilers above the fire-doors must also be carefully maintained.

The stoking with this type of boiler must be regular and methodical, which it is not always easy to obtain with a fresh draft of stokers. Several accidents have occurred with this type of boiler, but they have generally been due to overheating, consequent on shortness of water, and, in the early days to faulty manufacture or construction of tubes. The boiler is open to the objection, common to its class, of obstructions occurring between the inner and outer tubes.

M. Niclausse has lately introduced several improvements, among the more important is his new tube cleaner, which enables tubes to be thoroughly cleaned without taking down the side doors. The tubes can therefore be cleaned with a minimum amount of trouble to the *personnel* whenever necessary, an advantage, which in its turn is conducive to greater cleanliness of the heating surface, and therefore to higher efficiency. Cleaning is effected by fitting a hollow sleeve in place of a lantern here and there over the front of the boiler, through which the steam cleaning lance can be passed. It also enables the lance to be made of a fairly larger diameter, which permits of sufficient quantity of steam being blown through not only to clean the tubes, but also to leave their surfaces practically dry. Though

the use of the sleeve means the suppression of a few tubes, and therefore a slight reduction in the quantity of heating surface, it is more than compensated for in actual service by the greater cleanliness secured.

M. Niclausse has also recently introduced a superheater which he has used with considerable success on land work. It is placed in the centre of the nest of tubes, *i.e.*, about half way up, and with this arrangement it is said that a very uniform degree of superheat under widely different rates of working can be obtained.

131. *Dürr Boiler.—Montoupet Boiler.*—The Dürr boiler, of German origin, is also a derivative of the Field boiler; it is analogous to the Collet-Niclausse, but, unlike it, is not divided into elements, all the generating tubes being connected to a single flat water-space (Figs. 176, 176A, 176B). Trials of this boiler have been published, in which the combustion has been forced up to 70 lbs. per square foot of grate; but the efficiency must have been low, judging from what is known of the Belleville, Oriolle, Collet, and other boilers, when forced at such high rates.

The Dürr boiler is fitted on the German cruiser *Ersatz-Freya*, of 5,600 tons; at the same time two other sister ships are to be fitted with Belleville and Niclausse boilers; this series of trials will recall the similar ones recently made in France, on three cruisers of 3,750 tons, fitted with Niclausse, Belleville, and D'Allest boilers.

The Dürr boiler has since been adopted on several German vessels among which are the second-class cruisers *Victoria-Louise* and *Vineta*, on two large cruisers, *Prince Heinrich* and another vessel, and on three second-class battleships, *Baden*, *Bayern*, *Sachsen*, and on the training-ship *Rhein*. In the British Navy this class of boiler has been fitted on the *Medusa* and the *Roxburgh*.

The particular feature of the Dürr boiler consists in the arrangement of the tubes, which are slightly bent so as to form practically a tube wall with the tubes nearly touching each other, as illustrated in Fig. 176B. The

DÜRR BOILER.

Longitudinal Section.

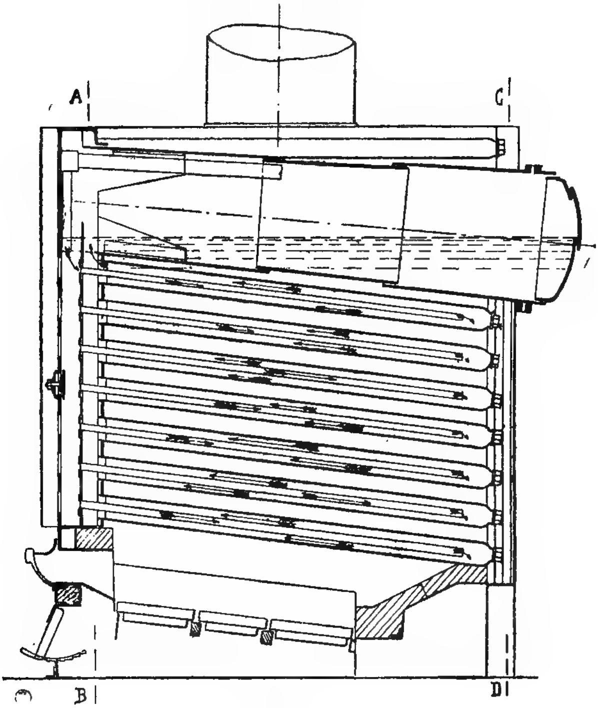


Fig. 176.

angle must not be too great, in order to provide sufficient room for passing in the inner tube.

M. Dürr was probably the first to modify the Collet boiler so that the whole boiler could be dismounted from the front. The present arrangement of the tubes is that shown in Fig. 177.

DÜRR BOILER.

Half section on CD. Half section on AB (Fig. 176).

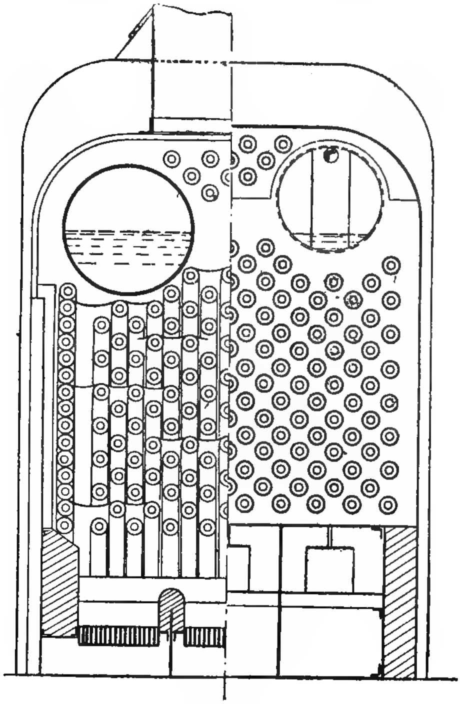


Fig. 176A.

JOINTS OF HORIZONTAL TUBES.

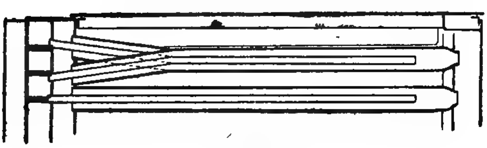


Fig. 176B.

The Montoupet boiler is a more recent derivative of the Collet boiler, dating from 1895. A front water-space divided down the centre by a baffle corresponds to the vertical headers of the Collet and Niclausse boilers. In tests carried out by the French naval authorities on some river boats in 1901, a good evaporation of 9.7 lbs. of water per pound of coal was obtained when burning 22.5 lbs. per square foot of grate.

ARRANGEMENT OF TUBES OF THE DÜRR BOILER.

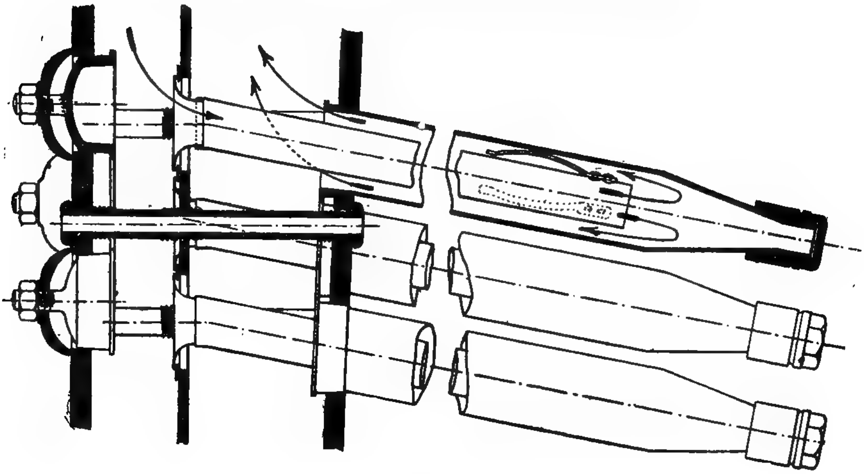


Fig. 177.

M. Montoupet gave up attaching the tubes to the front plate of the water-space and attached them only to the back plate. The external tube fits the back plate with a fairly sharp cone in order to insure the tightness of the joint, the steam tending to tighten them. The internal tube fits into the annular space, as shown in Fig. 178; the holes in the front plate are closed by an efficient form of door.

The practical details of this boiler have been well thought out; the tubes when hot are pressed up in a hydraulic press so as to give them the necessary thickness

for turning the coned joints; the cones are turned on the tubes and the tubes are then expanded into the back tube plate, and they can be re-expanded as occasion may require. A small collar is left on the end of the tubes to prevent them blowing out.

ARRANGEMENT OF TUBES IN THE MONTOUPET BOILER (1901).

(These tubes are inclined as in earlier boilers.)

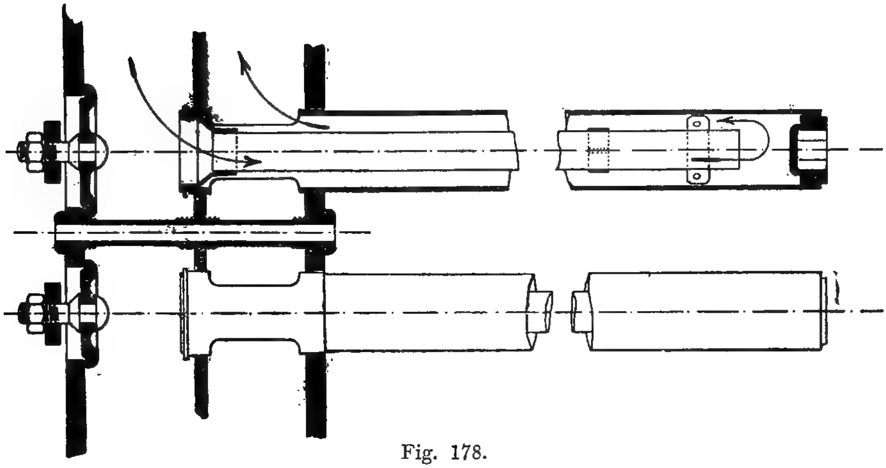


Fig. 178.

There are other types similar to the Collet boiler, such as the Pattison boiler made in Italy, and the Joya boiler described by M. Boutte during the Exhibition of 1900. Further types are referred to in paragraph 133.

132. *Charles and Babillot Boiler.*—The Charles and Babillot boiler, illustrated in Fig. 179, is also a concentric tube boiler. The gases circulate in the first instance around the outside of the big tubes, and then pass along the inside of the smaller tubes. The annular spaces containing the water are connected in front by a header for the escape of the steam, and at the back, with tubes for circulating the water. The arrangement naturally provides a large

amount of heating surface on a small weight. This type of boiler was fitted on the torpedo-boats *Sarrazin* and *Tourbillon*, also on the six torpedo-boats, Nos. 155 to 160, but the use of this type of boiler has not been continued. The narrow annular spaces between the tubes impeding the circulation led to the formation of steam pockets, and

CHARLES AND BABILLOT BOILER OF THE *SARRAZIN*.

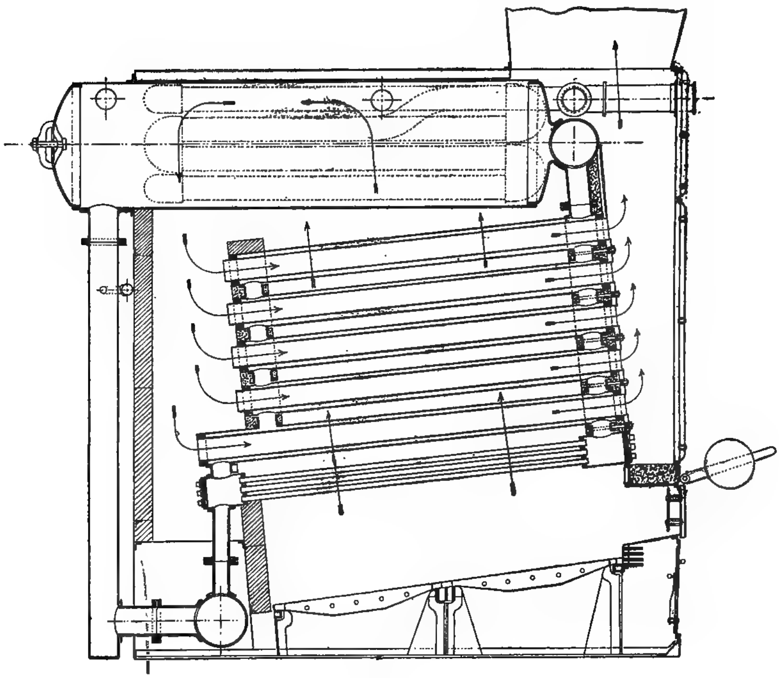


Fig. 179.

rendered this type of boiler extremely dangerous, when forced at the high rates usual on torpedo-boats. The repeated occurrence of accidents, owing to the lower rows of tubes becoming red hot, led, after the accident in January 1894 on board the *Sarrazin*, to the final condemnation of this type of boiler. One of the boilers built

for the torpedo-boats was fitted on to a little boat on the Seine where it was only worked at a very moderate rate, but a serious accident occurred in January 1900, when a tube blew out and six persons were severely injured.

133. *Various Types.*—The different types of boilers which have been briefly reviewed are far from forming a complete series, and several other types are mentioned in the Editors' work on "Water-Tube Boilers"*

Among these various types may be mentioned the Watt, Sinclair, Root, and Naeyer boiler. The Lencauchez or the Bourgeois-Lencauchez boiler, described in paragraph 126 has a derivative in the Terme-Deharme boiler used on the Paris river boats. The Kelly boiler is a type of Niclausse boiler; the tubes are divided into two portions by a partition running down the centre, but this arrangement has given rise to frequent accidents. The Lane and Menay boilers are similar to the Collet boiler; the Hérisson boiler is similar to the Field boiler, and resembles the De Dion-Bouton-Trépardoux boiler. The Turgan boiler is referred to at the end of the next chapter. Mr Irving and Mr Noble have designed a boiler similar to the Charles and Babillot boiler, where the flames pass through the centre of the internal concentric tubes. The types of boilers actually in use afloat are not numerous, and competition between them has led to increasing their efficiency and perfecting the details of construction. This is particularly the case in the boilers with accelerated circulation; a large number of different types have been recently brought out, being mostly, however, modifications of existing types. Boilers with free circulation are not as a rule worked at the higher rates obtaining with boilers of accelerated circulation, but several of the leading makers of the former type of boiler hope to compete successfully with boilers of accelerated circulation.

* "Water-Tube Boilers," Leslie S. Robertson. John Murray.

CHAPTER XIII.

BOILERS WITH ACCELERATED CIRCULATION.

134. *Movement of Water in a Circuit of some Height.*—The characteristic feature of all boilers having accelerated circulation is the creation and maintenance of a current of steam and water moving with a very much higher velocity than that at which the steam can possibly pass through the almost stagnant water in a Belleville boiler, or than that with which the steam can drag the water through a boiler having free circulation. The steam bubbles are detached from the heating surfaces, and carried towards the reservoir as quickly as produced, and are unable to accumulate and form steam-chambers, however high the rate of evaporation.

The means of ensuring this consists in causing the forces by which circulation is usually and naturally produced, to act upon a column of some height, and so disposing the down-take tubes returning the water from the top to the bottom reservoir, that they form a continuous circuit with the tubes carrying the steam from the bottom to the top.

The laws governing the movement of water containing steam bubbles, in a partly heated circuit, were for a long time very little understood. They have been carefully examined in some recent works and papers, amongst which may be noted, *Traité des Chaudières à Vapeur*, of M. Bellens, *Les Chaudières Marines*, by M. de Chasseloup-Laubat, a paper in the transactions of the *Société Technique Maritime*, by

M. Brillié, and various articles in the *Engineer*; and they have been the object of some interesting experiments on the part of several engineers, amongst whom Yarrow, Thornycroft, and Watkinson may be mentioned.

The movement of liquids in a complicated circuit can only be determined by actual experiment; although the velocities cannot be obtained, *à priori*, by calculation, yet they furnish us with useful information regarding the nature and relative value of the forces tending to produce movement.

M. Brillié has worked out some theoretical formulæ regarding the movement of the water in different types of boilers, and the results appear to be fairly accurate, but a detailed consideration of these is beyond the scope of the present volume, which is concerned with considerations of a general nature.

135. *Effects due to the Expansion of Water.*—Let us first consider the effects of a difference of temperature in a tubulous circuit such as $a\ c\ b$ (Fig. 180).

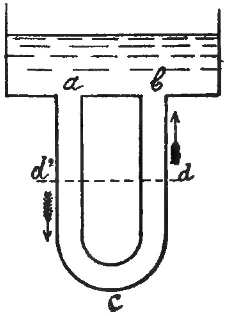


Fig. 180.

Let t be the temperature of the liquid. Suppose that at the point d, which is at a distance h below the upper orifice of the tube, the temperature is raised and becomes T. A current will be immediately set up and will be permanent when the column $d\ b$ has become filled with hot water. If "a" represents the coefficient of cubical expansion of the liquid then the force tending to produce movement, measured in height of water, is

$$p = h\left(\frac{1}{1 + at} - \frac{1}{1 + aT}\right),$$

or, neglecting the term in a^2.

$$p = h\,\frac{a\,(T - t)}{1 + a\,(T - t)}; \qquad (0)$$

which is sensibly proportional to $T-t$. The velocity of the current becomes constant when the resistance of the circuit equals the force p.

If the point d falls towards c, the height h increases, and the current is accelerated. If the point d, to which heat is applied, is then carried upwards along the branch $c\ a$, the velocity of the current is diminished, but its direction remains unchanged. When, for instance, the heat is applied at d', which is at the same height as d, the difference in pressure resulting from the difference of temperature t in $d'a$ and T in $d'cdb$ has the same value p as in the case just considered, and the velocity of the two currents would be the same. To ascertain the direction of the current it is therefore not sufficient to know which branch is heated, but which was heated first.

Supposing that, the source of heat being at d and the current moving in the direction of the arrows (Fig. 180), a fresh source, or sources of heat are introduced between d and b, the movement will be accelerated. For instance, there will be a higher velocity with two equal sources of heat at d and d' than with one source only at d—a result which at first sight would appear paradoxical.

The difference of pressures p given by the formula (o) cannot be great, owing to the smallness of the coefficient a; it should be particularly small in tubulous boilers, because the difference in temperature of the ascending and descending columns can hardly exceed 9° Fahr. when once the circulation is well started. Assuming $T-t$ equals 9°,

$$p=0.0005\ h.$$

For a height of 6.5 ft. the velocity should be 4 ins., neglecting the resistance to motion, but actually it would not exceed 2 ins. The movement due to the difference of temperature forms but a small proportion of the observed velocity, when the production of steam is actually taking place.

136. *Effects due to the Production of Steam Bubbles.*—The rapid circulation in the class of boilers now under consideration is due to the action of the steam bubbles in the ascending portion of the circuit.

A steam bubble of a specific gravity δ, in a liquid of a specific gravity Δ, supposing there is no resistance to its movement, will rise with an acceleration W determined by the equation:

$$(1) \qquad \frac{\delta}{g} W = \Delta - \delta,$$

in which δ in the second expression is negligible in the presence of Δ. There remains, therefore,

$$(2) \qquad W = g\frac{\Delta}{\delta}.$$

For example, with a temperature of 368.5° Fahr., and a pressure of 170.7 lbs. per square inch, we get

$$\Delta = 0.887$$
$$\delta = 0.006$$
$$W = 4{,}760 \text{ ft. per sec.}$$

The resistance offered by the liquid at once checks this enormous acceleration, and limits the velocity of the bubbles through the water to a slow and uniform movement.

Let us consider the movement of bubbles of a diameter D passing through the water with a velocity V and experiencing a resistance R, the same as if they were solid balls. The value of R in terms of the velocity V, is, in default of proof to the contrary, given approximately by the equation—

$$(3) \qquad R = K \times \tfrac{1}{4}\pi D^2 \times V^2.$$

K being a coefficient of resistance taken formerly as equal to 0.95 the force acting on the bubble is exactly

$$(4) \qquad 62.4 \times \tfrac{1}{6}\pi D^3 (\Delta - \delta).$$

When the movement is uniform the resistance is equal to the force producing movement, hence

$$(5) \qquad V^2 = 62.4 \times \tfrac{2}{3} (\Delta - \delta) D.$$

In the above formula $(\Delta - \delta)$ has been taken as 0.881, the foot and pound having been taken as units in formula (3). The value of K has been estimated by M. Brillié as 2.28 from experimental measurements of the velocity V. We then have

$$V^2 = 16.65\ D.$$
$$V = 4.08\sqrt{D}.$$

V and D being measured in feet.

The velocities given by this formula are low, whatever the diameter of bubble.

They are almost negligible with very small bubbles of less than .04 in. in diameter enclosed in a rapidly moving current. For instance, if

$$D = 0.08 \text{ in.} \qquad V = .328 \text{ ft. per sec.}$$
$$D = 0.008 \text{ in.} \qquad V = .102 \text{ ft. per sec.}$$

for a diameter of .8 in. the velocity would be 1.02 ft. per second. As the velocity in this type of boiler has been observed to reach about 2 ft. per second at the entrance of the tubes, and over 3 ft. per second at the outlet the minute bubbles carried up in the emulsion may be looked upon as stationary compared to the velocity of the water in which they are moving.

It is interesting to note the volume of steam and the corresponding number of bubbles produced in a tube. Boilers with accelerated circulation can evaporate 10.24 lbs. of water per square foot of heating surface per hour; this gives 104 lbs. or 27.7 cubic ft. of steam at 171 lbs. pressure per square inch in a tube of 1.18 ins. internal diameter and 3.28 ft. long. In such a tube 52,000 bubbles of 0.08 in. diameter would be produced per second, or 52,000,000 bubbles of 0.008 in. diameter.

Applying these calculations to cases where the pressure reaches 284 lbs., about the average for tubulous boilers, the figure relating to the volume of steam should be reduced in

the proportion 0.621. The value $\Delta - \delta$ becomes at the same time 0.877.

Bubbles moving at a uniform velocity encounter a resistance to their passage through the water of

$$62.4 \times \tfrac{1}{6} \pi D^3 (\Delta - \delta),$$

equal to the force with which the bubbles react upon the water. The sum of these reactions, however, distributed throughout the particles of the liquid has the same effect as a reduction in the specific gravity of the liquid; this may be demonstrated by a simple experiment, which also shows that the increase in hydrostatic pressure is sensibly equal to the unbalanced forces acting upon the bubbles and causing them to rise.

If a cylindrical vessel containing water is placed upon a balance, and steam-bubbles have just commenced to form and rise with a uniform velocity, no change in weight will be indicated. The level will rise from a to b, owing to the displacement of the bubbles (Fig. 181); the height h will become h_1; the mean specific gravity δ will become δ_1; and therefore,

$$\delta_1 h_1 = \delta h. \tag{6}$$

If there had been an outlet at a the pressure on the bottom of the vessel would have been reduced in the proportion—

$$\frac{h}{h_1} = \frac{\delta_1}{\delta}.$$

Similarly in a U tube, of which one branch only contains bubbles (Fig. 182), the level in this branch will rise from a to b while remaining stationary in the other branch. There is therefore equilibrium at the bottom of the syphon; but if an opening be made at a, there will be an overflow due to the difference of pressure—

$$h_1 - h = h\left(\frac{\delta}{\delta_1} - 1\right). \tag{7}$$

Let us now consider the case of a U tube as in Fig. 183, having provision for circulation in the shape of a return tube, or down-take C, which is not heated and is in communication with the branch B, in which bubbles are produced.

Without steam bubbles, the level in the tubes, when at rest, will be the same, a' and a'', and the columns of water in A and C will be in equilibrium with the column of water and steam in B, where the level is at b. On account of the

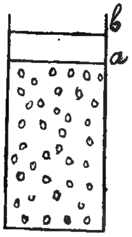


Fig. 181.

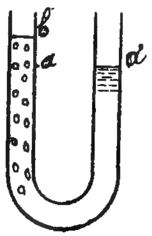


Fig. 182.

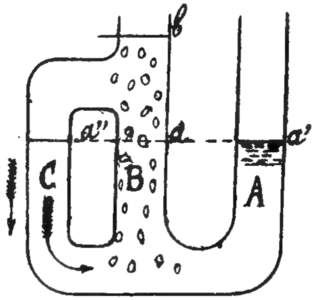


Fig. 183.

communication between C and the top of B, the pressure at the bottom of C will be increased by the difference in head $h_1 - h$, and circulation will take place due to this difference. The current will attain its normal velocity when the resistance opposed to its movement counterbalances the difference in head $h_1 - h$.

Circulation will also be established if the branch B delivers into the branch C, as shown by Fig. 184, but under different circumstances. This arrangement, shown in Fig. 184, is conducive to a steady and uniform rate of circulation.

There will be a discharge from the extremity of the tube B on account of the difference of level between this orifice and the height of the column in C, necessary for equilibrium. This case represents the mode of circulation of several types

of boilers, and in particular that of M. Sochet, which was the first having accelerated circulation.

The statements previously made regarding the permanence of the currents produced by an initial difference of temperature in the two branches of a circuit *a c b* (Fig. 180), apply equally to the currents produced by the movement of steam bubbles. We must, however, suppose that the velocity of the water is in all cases greater than that of the bubbles relatively to the water, the movement always taking place in an upward

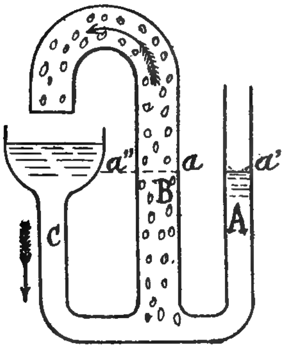


Fig. 184.

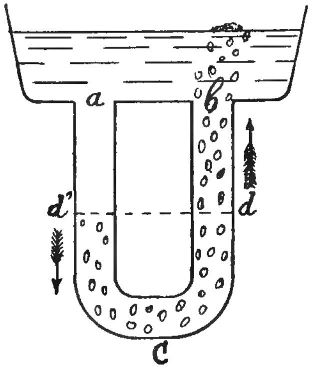


Fig. 185.

direction; if this condition is not fulfilled, the direction of the current might be reversed.

If we again take the vessel shown in Fig. 180, and heat the branch *c b* of the tube *a c b*, at a point *d*, so as to produce steam bubbles at this point (Fig. 185), a current will be formed under the action of a hydrostatic pressure equal and opposite to the resistance offered by the water to the passage of the bubbles. If the point *d* is lowered, the number of bubbles contained in the tube will be increased, and the velocity of the current will also be increased. If the point *d* now passes to the left branch, the velocity of the current will be decreased, but without any change in its direction, the direction of motion originally set up being maintained,

whether the source of heat is applied at d' or d. The application of additional sources of heat, in whatever positions, will, within certain limits, increase the velocity of the current.

Finally, when the velocity of the bubbles in relation to the water is negligible, as is the case in boilers with accelerated circulation, the movement of the water under the conditions shown in Fig. 185 is not reversible. The velocity depends on the position of the source of heat; the direction of the water depends on the initial conditions alone.

With glass tubes heated by Bunsen burners, Mr Yarrow made some interesting experiments on the laws regulating the circulation of water.

It may be noted that the current set up by the production of steam bubbles, produced at a constant rate, should be of a more permanent and uniform character than that due to the lowering of the specific gravity of the ascending column. In fact, if a reduction of velocity takes place, the steam bubbles accumulate in greater quantity in the ascending column, and the difference in specific gravity in the two columns increases by virtue of the reduction in velocity. There are thus two forces at work tending to restore the circulation to its normal velocity.

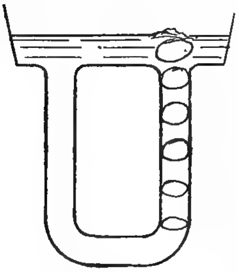


Fig. 186.

A special case, where the current is due to the production of steam bubbles, and not to the heating of the liquid, is that where the tube is of such a small diameter that the bubbles fill the whole section.

The liquid column is then broken (Fig. 186), and if there were no return tube an upward movement would be impossible, contrary to the case illustrated by Fig. 181. Supposing circulation to have already been established, the fall of pressure produced would be equal, as in the preceding cases, to the reduction in the mean specific gravity

of the ascending column, only in this case the reason for the fall of pressure is more evident than in the preceding case. The resistance opposed to the circulation, and consequently the laws governing its velocity, would be very different to those in the case of Fig. 185.

137. *Comparative Effects of Evaporation and Expansion.*—The principle of the *entraînement* or setting in motion of the water by the action of steam bubbles being thus established, the head of water corresponding to the action of the bubbles can be calculated in a simple manner by assuming certain, not improbable, hypotheses regarding the velocity of circulation of the water. Again, considering the tube of 1.18 ins. internal diameter, and generating per hour and per foot of length, 27.72 cubic ft. of steam, of a specific gravity of 0.006, if the tube heated is 6.56 ft. long it will deliver 55.4 cubic ft. of steam per hour at its upper orifice. Supposing that, while heated, the velocity of the current of circulation is 3.28 ft. the total output of the tube is 0.25 cubic ft. per second, or 90 cubic ft. per hour. The mixture of water and steam discharged from the orifice is therefore composed of three parts of steam and two of water. The water is thus subjected to a circulating force which, at the top of the tube, amounts to three-fifths of the specific gravity of an equal column of solid water without steam bubbles, that is to say, about two thousand times greater than the effect produced by a rise in temperature of 9° Fahr.

Under these conditions the velocity of entrance of the water at the bottom of the tube is, neglecting the weight of steam as compared to the weight of water present,

$$\tfrac{2}{5} \times 3.28 = 1.31$$

The proportion of the water not evaporated to the steam is thus

$$\frac{2}{3} \times \frac{.887}{.006} = 98.55$$

or approximately 100. These figures agree fairly well with data gathered from observation.

The above reasoning is applicable to cases where, instead of generating steam, bubbles of gas are introduced at uniform rates at the point *d*; this method has been used by Mr Yarrow for the purpose of his experiments. Steam bubbles possess the peculiarity of condensing, and of partially reforming while rising and falling, owing to variations of pressure.

138. *Application of these Principles to Circulation of Boilers.*—In actual practice, the above speed of circulation

$$U = \sqrt{2\,gp},$$

which corresponds to the difference of pressure p, is far from being attained. In fact, if on a very small height dh, taken at the top of the tube, the small depression, as we have seen, is

$$dp \times \tfrac{3}{5} \times dh,$$

dp being zero at the bottom of the tube, where there are no steam bubbles, the total depression for the whole tube ought to be

$$p = \tfrac{3}{10}h$$

and even more.

Supposing h to be equal to 5 ft. the velocity U would reach 10 ft., five or six times greater than that shown in actual practice. The difference is explained by the importance due to the loss of head in the ascending current of the generating tubes, in the descending current of the return-tubes, and especially in the passage of the drums.

The formation and the *entraînement* of the steam, in the form of an emulsion is one of the characteristics of the new types of boilers, and indicates that there is a sufficiently pronounced circulation to prevent danger of burning or excessive incrustation of the tubes. In the early

stages of getting up steam the generating tubes discharge the steam in sudden puffs and with a geyser-like action, but as soon as the circulation is thoroughly started the discharge becomes regular. This shows that the steam is swept off the sides of the generating tubes, instead of allowing the steam bubbles to form a steam-pocket, which would rise owing to its hydrostatic head.

Everything possible should be done to assist the circulation, by encouraging all that tends to produce steam, removing as far as possible any causes tending to reduce the circulation, as the efficiency of a boiler increases with the speed of circulation. In war vessels provision must be made for the boilers to evaporate 10 lbs. per square foot of heating surface per hour, and at ordinary rates of working, they must be capable of evaporating about 4 lbs.

To secure this, the proportion of the volume of steam to water in the ascending currents is increased by reducing the diameter of the tubes, and the resistance to the descending currents is diminished by increasing the diameter of the down-comers, and making them as large and as straight as possible. At first it used to be thought that the down-comers should be kept cool, but the advisability of keeping them warm has now been recognised, because the increase in lightness of the water due to the heat imparted in the down-comers adds to the increased lightness of the ascending column. The heating of the feed-water is particularly useful, as the water is then in a position to take up the heat more readily.

A question which has attracted considerable attention is the limiting proportion of steam to water, which can be attained — but not exceeded — in the generating tubes. M. de Chasseloup-Laubat suggests a half as the most suitable proportion. This proportion will no doubt vary with different types of boilers, but there must always exist some proportion which will give the maximum output. Anything

under this will retard the current, and too high a percentage of steam will not leave sufficient water to absorb the heat transmitted through the heating surfaces. These remarks refer to the volume and not the weight of the steam and water. The proportion of the weights will increase directly as the pressure. The weight of water, that boilers with accelerated circulation can evaporate under good conditions, increases with the pressure.

The circulation would be still further increased if the water could pass from one tube to the other without traversing the receivers or drums, but boilers embodying this arrangement have not been brought to a successful issue. Boilers with accelerated circulation which have lately been so largely adopted, were first used at Cherbourg over fifty-five years ago, when the first experiments on this type of boiler were being made.

139. *History of Boilers with Accelerated Circulation.—Sochet Boiler.*—When a new form of boiler or other apparatus suddenly becomes extensively adopted, it is frequently discovered that long ago there existed examples, which in their day received but little attention. Such instances are not wanting in connection with the type of boiler now under consideration. According to Mr Seaton's "Manual of Marine Engineering," there existed in 1827 a tubulous boiler composed of a steam reservoir and two steam and water reservoirs connected by tubes, the arrangement being strikingly analogous to that of some of the most recent examples. They were first used on traction engines.

The introduction on a practical scale of boilers with accelerated circulation for marine propulsion is largely the work of Captain Du Temple. He was, however, anticipated by M. Sochet, Director of Naval Construction at Cherbourg. The result sought by M. Sochet was simply the production of a boiler with rapid circulation; in fact, this

was the name he gave to his boiler. His object was to prevent the disposition of hard adherent calcareous deposits upon the heating surface, and not with a view of avoiding the formation of steam chambers at high rates of evaporation which were not then contemplated. His idea was that the marine salts would solidify in a finely divided state, be carried over by the circulating current, and deposited in an extractor or settling drum, from whence they could be discharged by blowing-off. The problem was to construct a marine boiler capable of being worked at a high pressure in connection with jet condensation. The use of high pressures with fresh water was also contemplated.

The Sochet boiler designed for use on board ship, fulfilled the ideas of Dupuy de Lôme, who desired to use high pressure boilers with fresh water from surface condensers. After the construction of a one horse-power boiler M. Sochet made, in 1857, a four horse-power boiler, illustrated in Figs. 187, 187A.

The Sochet boiler, primarily intended for service afloat, was only tried on land for workshop purposes. Fig. 187 shows its general arrangement, which exactly corresponds to that now universally adopted for this type of boiler. The circulation is complete, the steam being produced in the ascending portion of the current, and the water returned by a large external down-take. It will be noticed that the steam is discharged above the water-level in the reservoir, as in the earlier types of the Thornycroft boiler. M. Sochet also contemplated blowing air into the ashpan.

The Sochet boiler worked at a pressure of 71 lbs. per square inch and evaporated 7.35 lbs. of water per lb. of coal, while burning 15.36 lbs. of coal per square foot of grate per hour. The grate area was 5.38 sq. ft., and the heating surface 75.35 sq. ft. On the termination of these trials, M. Sochet in 1861, acting on orders from M. Dupuy de Lôme, prepared designs for a 6000 horse-power boiler,

the arrangements of which were not so simple as those shown in Fig. 187, and the design was consequently rejected, a Rowan boiler being fitted in its place on the despatch boat *Actif*, and tested in 1862.

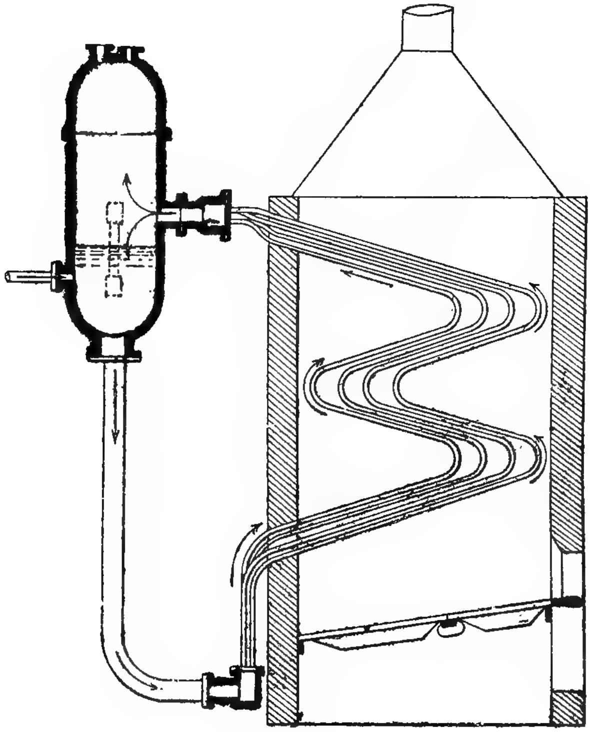


Fig. 187.

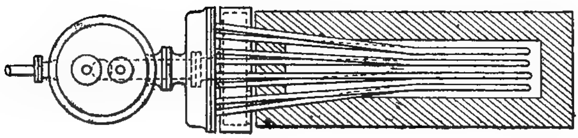


Fig. 187A.

At the date at which it was put to work, the Sochet boiler, no doubt, appeared to require very delicate handling; besides, it offered no great advantage when used on shore,

and was abandoned about 1859 and replaced by an ordinary boiler.

M. Sochet, who was the Author's chief in 1862, spoke very little of his boiler, but later on, the Author heard it referred to in the boiler shop, where it was well remembered; the manager of the shop, M. Bigot, a very capable engineer, fully appreciated the advantages of rapid circulation for light boilers containing very little water. M. Du Temple himself does not appear to have had any direct knowledge of the experiment made by M. Sochet, but the workmen, first employed by him had seen the boiler just described, and this probably accounts for the similarity in shape of the curved tubes shown in Fig. 187, and those of the early Du Temple boilers.

140. *Du Temple Boiler.—Original Form.*—Commander Du Temple designed his first boiler with the object of applying it to purposes of aerial navigation. It was designed with a view of supplying steam to an engine driving the helical propeller of a kind of aëroplane, an invention to which M. Du Temple devoted the whole of his fortune and a part of his life, particularly after 1876, when he retired from political life. The aëroplane was a failure, but the boiler survived. In 1878, it was fitted to a few launches, and afterwards to some torpedo-boats, and has now become the most extensively adopted type of boiler for use under high rates of forcing, whether in its early form, or as altered by different makers. Unfortunately, this took place at the moment when its inventor had just passed away.

The general form at first given to his boiler by M. Du Temple has not since been departed from, and is similar to that adopted by the majority of other makers. Two small water-chambers at the sides of the furnace form the lower portion of the boiler. The steam reservoir is placed

above, with the water-level at about its centre. The generating tubes connect the steam and water reservoirs and discharge below the water-level. Large external down-takes at the front and back of the boiler serve to return the water from the upper to the lower reservoirs, and complete the circuit of circulation. Fig. 188 represents this arrangement, and at the same time shows several details which have for a long time been in use, and are also embodied by the inventor in his last patents in 1890.

The distinguishing characteristics of the Du Temple boiler properly so called, when compared with the improved and perfected forms which have since appeared, are (*a*) the use of tubes bent into several folds with five straight portions, but slightly inclined to the horizontal and successively crossed by the hot gases; and (*b*) the use of cast-iron bottom chambers of rectangular section. The furnace gases ascend almost vertically. At first, Du Temple attached great importance to the use of very thin and small tubes of about 0.4 in. diameter. He found that by their use he could obtain a larger heating surface, and also a minor advantage, in the facility with which a burst tube could be stopped by simply closing it together near the ends by means of a pair of pincers. He was himself, however, obliged to abandon this primitive method of tube-stopping. The tubes of the boilers for torpedo-boats Nos. 130 to 144, ordered in 1889, were of 0.51 in. internal diameter, and about 0.67 in. external diameter. Du Temple retained till the last the cast-iron bottom chambers, which were provided on the outside with a number of small hand-holes.

The disadvantages of the Du Temple boiler in the form which its inventor finally gave to it principally affect its durability. The circulation in the very sinuous generating tubes was comparatively slow, from which circumstance arose the danger of the formation of deposits, especially in

the nearly horizontal portions next to the bottom reservoirs, and also the danger of the formation of steam-chambers in the tubes. As soon as an obstruction commenced to

BOILER OF "DRAGON."

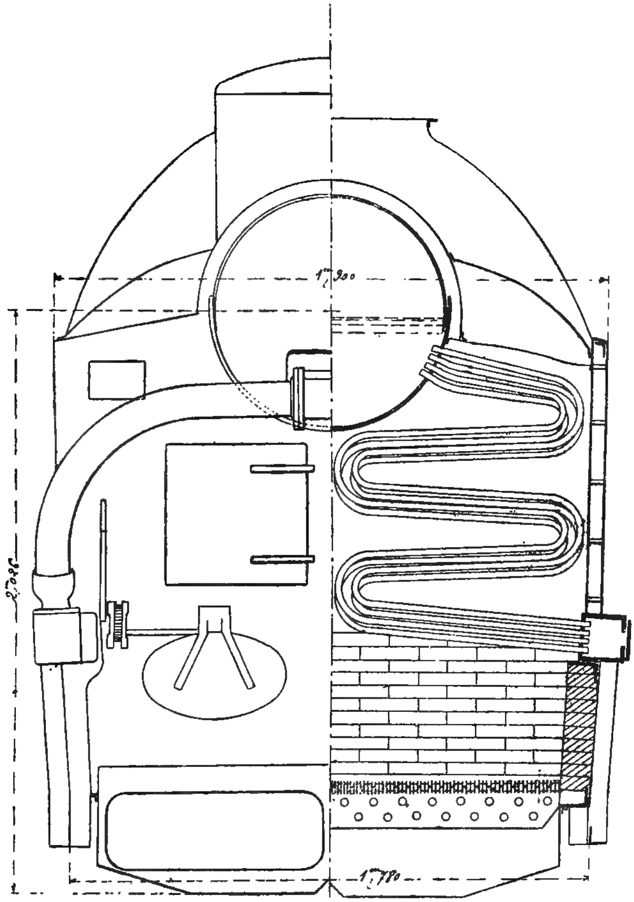


Fig. 188.

form in a tube, the circulation was still further retarded and the danger increased, so that the tube was bound to burn through in a very short time. The *Dragon* gave

occasion for complaints of this nature whilst serving with the squadron, and the same thing occurred on the three torpedo-boats Nos. 186, 190 and 191, during the trip they made from Cherbourg to Toulon in 1895. It should, however, be mentioned that the engineers, who were unaccustomed to the management of tubulous boilers, did not take sufficient care to ensure the purity of the feed-water, and to maintain the water level. The accident to the boiler of the *Averne*, where the lower portions of the generating tubes were entirely burnt away during a passage from Cherbourg to Brest, can only be explained by a prolonged shortness of water.

The early Du Temple boilers suffered from the smallness of their combustion chambers, which were hardly larger than those of the Belleville boiler. Owing to this, combustion was incomplete, due to cooling of the gases by premature contact with the generating tubes, and at high rates of forcing this gave rise to excessive flaming at the top of the funnel. In this respect, as in that of evaporative efficiency, the Du Temple boilers are no worse than the locomotive boilers which they have been called upon to replace on several torpedo-boats.

141. *Successive Improvements in the Du Temple Boiler.—The Du Temple-Normand Boiler.—The Guyot Boiler.*—The Du Temple boiler has been the object of numerous improvements, the enumeration of which would almost constitute a history of boilers with accelerated circulation. Some of these improvements have been introduced by the different engineers, who since 1890 have been at the head of the Du Temple establishment, but the most important are due to the makers, who successively joined the movement in favour of the new system of boilers, and in particular to M. Normand, whose improvements have since been adopted by the Du Temple firm.

Sir John Thornycroft was the first in England to apply tubulous boilers to torpedo-boats, and most probably the first to use, in the form adopted in his boiler, the method of forming screens or walls by means of tubes in contact with each other. In general arrangement the Thornycroft boiler is quite distinct from the Du Temple type. M. Normand, whose conversion to the new system largely influenced its success in France, worked at the outset in collaboration with the Du Temple firm, and the Du Temple series of boilers includes several mixed types of Du Temple-Normand boilers, before the present form of Du Temple boiler (which differs very little from the Normand boiler itself), was arrived at.

As it is difficult to follow in strictly chronological order the improvements in the Du Temple boiler, only the most recent changes will be noted. One of these was the abandonment of the lower rectangular cast-iron collectors in favour of cylindrical wrought-iron ones. Independent of the fact that they were inferior in design, the rectangular collectors gave a wrong direction to the lower ends of the tubes. These, which should be vertical at the junction of their lower ends with the collectors, in order to facilitate the settling of solid deposits in the bottom reservoirs, had with the rectangular collectors, a horizontal direction. The bottom drums are inspected by means of a single manhole in the boiler-front.

The diameters of the tubes and the forms into which they are bent have been frequently modified, but always in the direction of increased diameter and simplified form.

The boilers of the torpedo-boats Nos. 130 to 144, built in 1889, had tubes of 0.67 in. external diameter. In ten torpedo-boats, No. 145 type, tubes of variable diameters were employed, having a diameter of 0.75 in. over the lower horizontal portion, and 0.94 in. over the remaining length of the tube; the thickness was at the same time increased

from 0.079 in. to 0.098 in. The diameter was made variable with the object of facilitating the escape of steam from the upper portions of the tube. In 1893 the tubes were made 0.98 in. in external diameter at the lower portion, and 1.18

BOILER OF THE "CHEVALIER."

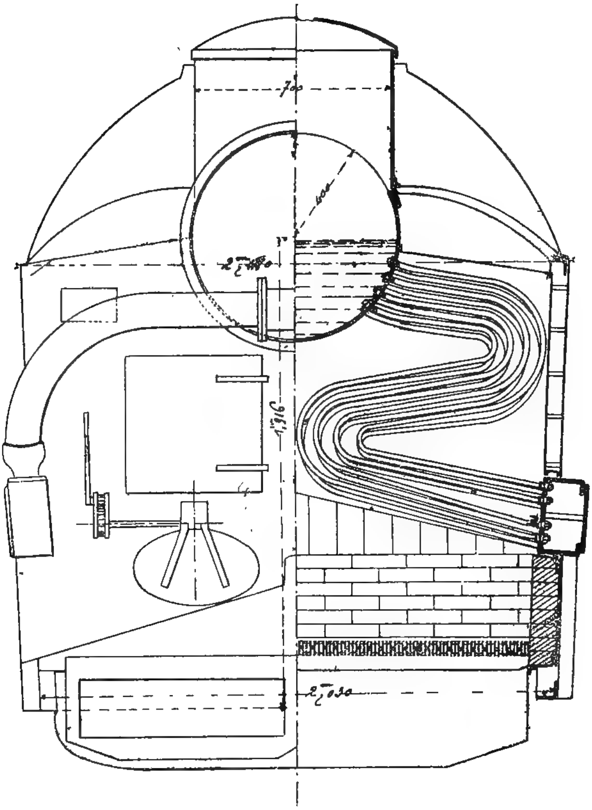


Fig. 189.

ins. for the upper portion, with a uniform thickness of 0.118 in. As now made, the external diameter is uniform, and equal to 1.38 ins.

A simplified form of tube is found for the first time in the

boiler of the *Chevalier*, represented by Fig. 189, where the tubes are only bent over twice instead of four times. This type, at 213 lbs. pressure per sq. in., has been adopted for a good many boats, the *Lancier*, *Corsaire*, *Mousquetaire*, torpedo-boats Nos. 145, 146, 154 to 159, 170 to 181, etc.

The Du Temple establishment continued to use this form of tube, with the gases always passing across the tubes, up to 1896. In the latest boilers of this type—represented by Figs. 190 and 190A—the disadvantages inherent in this form, as regards the utilisation of the heat, have been almost eliminated. The tubes rise vertically from the upper portions of the bottom drums and form a high arch over the grates, giving a good lofty furnace. A partial baffle is formed by arranging the tubes close together, causing the gases to take a transverse direction; a baffle of sheet metal, placed under the funnel, forces the gases towards the two ends of the boiler, so as to obtain about the same duty from the tubes near the ends as from those in the centre of the boiler. Another arrangement of generating tubes, as proposed by the Du Temple firm, may be mentioned, in which the tubes, rising from the bottom drums, cross each other in the centre, those rising from the right-hand bottom drum being connected to the left hand of the top drum, and those from the left-hand bottom drum to the right hand of the top drum. This arrangement has been used by M. Nabor Soliani, and also by a Swedish designer.

At present the Du Temple establishment is abandoning the use of tubes bent into several folds, with a transverse direction of the gases, in favour of the return flame type, the superior efficiency of which cannot be questioned. The tubes form a wall around the fire, and combustion is even more complete than in the furnace of a cylindrical boiler. The hot gases, returning among the banks of tubes, pass from end to end of the boiler before escaping into the funnel.

MANGINI.
DU TEMPLE BOILER.

Longitudinal section.

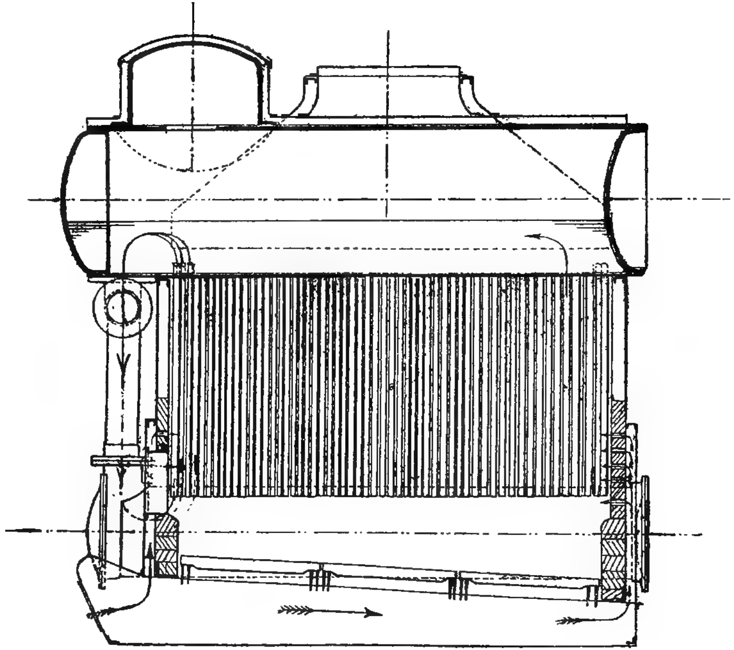


Fig. 190A.

Half section. Half elevation.

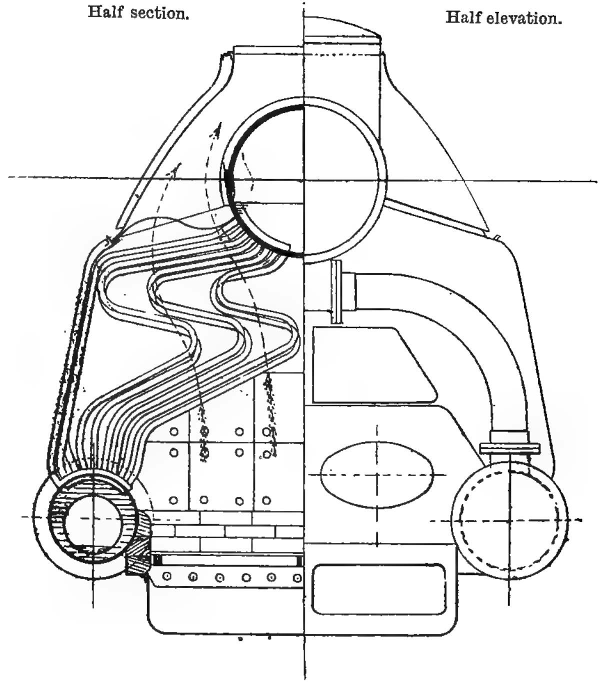


Fig. 190.

The tubes forming the closed walls or baffles, by the aid of which it is now possible to direct at will the current of gases in tubulous boilers, and even to surround the

DU TEMPLE-GUYOT BOILER.

Longitudinal section. Half section. Half elevation.

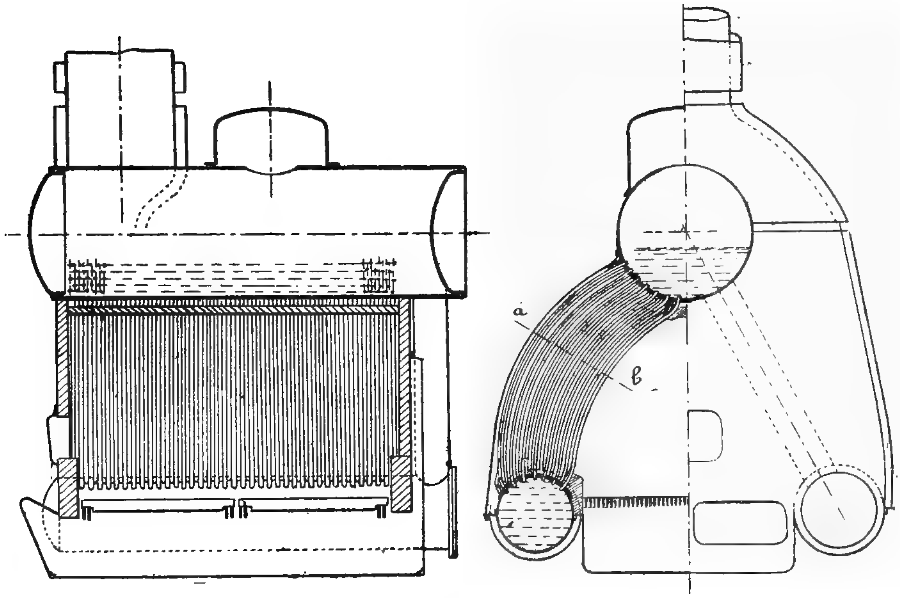
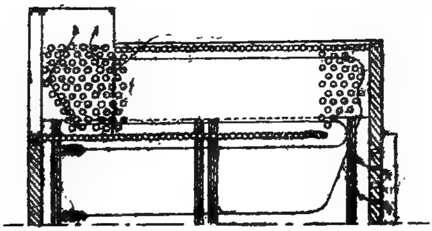


Fig. 191.



Section on *a b*.

Figs. 191A and 191B.

whole boiler with a water wall or jacket, are worthy of notice. It is obvious that the tubes cannot be in contact for their entire length, on account of jointing them with the reservoirs. The walls are formed by bending into the

same plane the tubes of two neighbouring or contiguous rows, so arranged that the space between two of the tubes exactly corresponds to the external diameter of the tube in the other row. The short triangular spaces, which are unavoidably left at the ends of the tubes, must be closed by fire-brick or asbestos, especially at the upper ends, so as to prevent any passage of the gases. It may even be necessary to use a light backing of fire-brick or asbestos behind the tube-walls, in order to obtain the desired tightness and, in order to fill completely any interstices which may exist between the tubes in the same plane, a small thread of asbestos is packed in between them.

The type of Du Temple boiler represented by Fig. 191 was designed by M. Guyot, an engineer at Cherbourg, and the following are the particulars of the boilers under construction at the end of 1896, and intended for torpedo-boats Nos. 206 to 211 :—

		1896 TYPE.	1901 TYPE.
Grate area	sq. ft.	24·54	25·6
Heating surface	sq. ft.	1,130·25	1185
External diameter of generating tubes	ins.	1·024	1·00
Thickness of generating tubes	in.	0·098	0·098
Weight of boiler empty, funnel and mountings included	tons	5·71	6·38
Weight of water	tons	1·427	1·43
Boiler pressure	lbs.	225	225

M. d'Aboville, manager of the Du Temple works, uses for the tube wall tubes specially drawn for that purpose, and illustrated in Fig. 192. This arrangement allows the tubes to move relatively to each other without in any way impairing the tightness, and the wall has so far given complete satisfaction.

The method of connecting the tube-ends to the barrels by screwed joints forms a constructive detail which was adopted from the first, and is still occasionally employed

by the Du Temple establishment. This joint is shown in Fig. 193, and consists of a cone and nut screwed on to the ends of the tubes, the plate of the barrel being gripped between them. The engineers of torpedo-boats have generally reported well of this arrangement, which facilitates

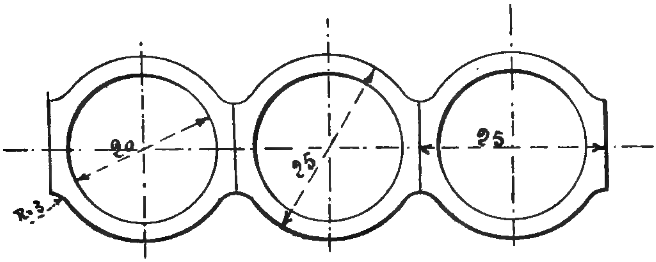


Fig. 192.

replacing the tubes, and almost always permits of "plugging." Its disadvantage is an enlargement of the holes in the barrels, and consequently the tubes have to be spaced further apart.

The cones and nuts were, until recently, of brass, but steel has now been adopted, so as to avoid galvanic action. The steel cones are screwed on to the tubes, and then fixed in position by slightly expanding the tube.

CONNECTION OF A GENERATING TUBE TO THE UPPER DRUM.

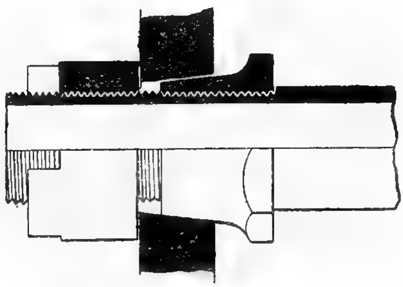


Fig. 193.

On the occasion of an accident to the upper drum of the *Chevalier*, in 1894, caused evidently by shortness of water, this form of joint proved, in a remarkable manner, its ability to withstand rough treatment. The drum was permanently enlarged (on one side only), where perforated by the tubes, in such a way as to form a longitudinal pocket, the

plates being about an inch out of the true cylindrical form. All the tube-holes became oval, with the major axis transversal to the boiler. The cones and nuts remained in place, and all the joints held well.

In some of the boilers the coned joints have been replaced by the ordinary expanded tube joints.

142. *Normand Boiler.*—The part taken by M. Normand in the successive improvements of the Du Temple boiler, from the time when he commenced to adopt it in place of locomotive boilers for his torpedo-boats, may be shown by comparing the two Figs. 189 and 194. The latter represents the Du Temple boiler as constructed by M. Normand for the *Flibustier*, the *Ariel*, and torpedo-boats 186 and 187, and is appropriately called the Du Temple-Normand boiler, from which the later types of the Du Temple boiler, Figs. 190 and 190A, are evidently derived.

M. Normand, applying to his work the methodical care and attention to detail which have gained for him such a high reputation as an engineer, designed several new and original types which retained, however, the general arrangement of the Du Temple boiler, while embodying some of the features of the Thornycroft boiler, with this important difference, that the current of hot gases has a horizontal instead of a vertical direction.

The first point to which M. Normand directed his attention was the shape or form given to the generating tubes, which he simplified by discarding the lower folds —a relic of the Sochet boiler. His tubes are only curved sufficiently to give them the required elasticity, and to bring their ends normal to the tube-plates.

In order to make the passage of the gases amongst the generating tubes of sufficient length, M. Normand gives them a longitudinal direction. With this object he designed

TORPEDO-BOAT No. 186.

DU TEMPLE-NORMAND BOILER.

Longitudinal section.

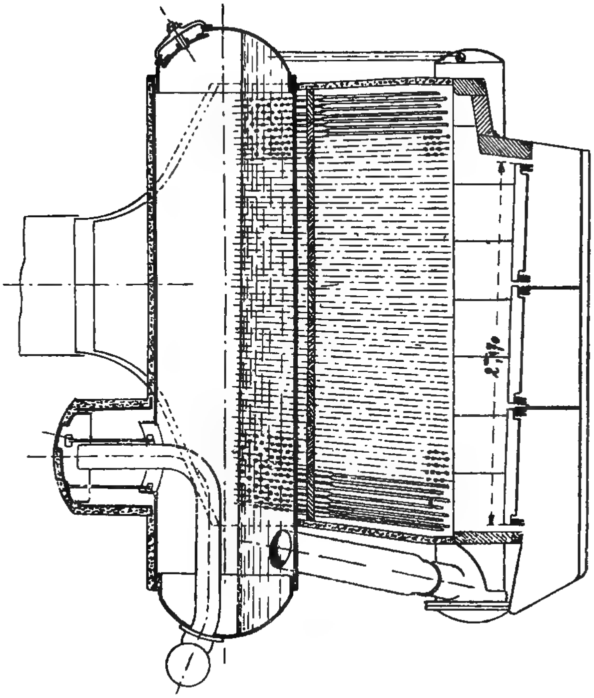


Fig. 194A.

Half section. Half elevation (from back).

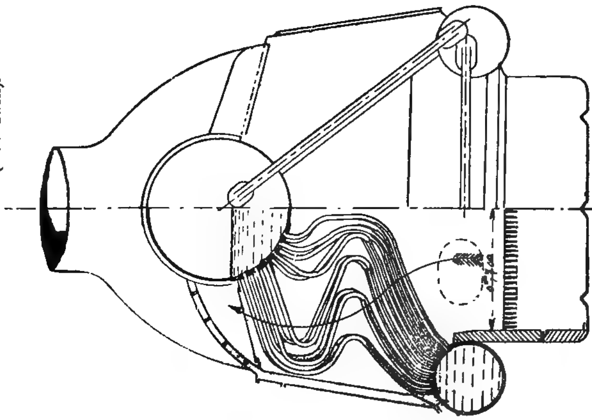


Fig. 194.

in 1890 and 1893 two different arrangements to suit the varying position of the funnel (Figs. 195 and 196).

When the funnel is towards the front of the boiler, as on the *Aquilon*, the flames pass first to the back of the furnace where they split up and return towards the front,

FORBAN.

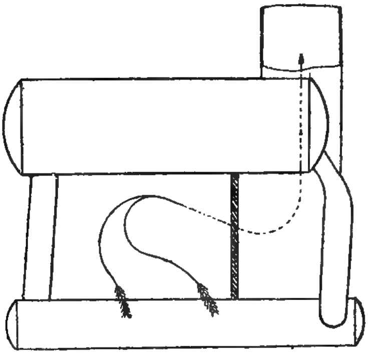


Fig. 195.

AQUILON.

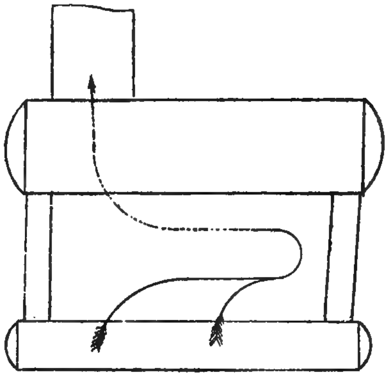
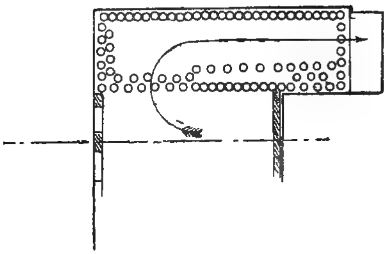
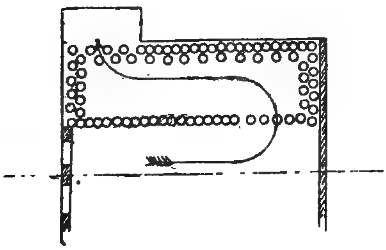


Fig. 196.



Half sectional plan.
Fig. 195A.



Half sectional plan.
Fig. 196A.

passing among the generating tubes on their way, the direction taken being thus analogous to that followed by the gases in the ordinary marine return-tube boiler. The gases escape into two smoke-boxes at the sides of the boiler. This form is known as the "return-flame" type.

When the funnel is towards the back of the boiler, as on the *Forban*, the opening for the furnace is at the

front, the back of the furnace being completely closed by a fire-brick partition; the hot gases therefore first pass towards the front, where they split up and return along the flues, formed by the generating tubes, to the back of the boiler from whence they escape into breeches-shaped smoke-boxes. This form of boiler, in contradistinction to the foregoing one, is known as the "direct-flame" type—a purely conventional term, as both types are in fact "return-flame," but the "return" is not so complete in the case of the "direct" type, and, moreover, its direction is reversed. The boilers are similar in other respects, except as regards the positions of the furnace and ashpit doors.

M. Normand usually prefers the "return-flame" type, and his opinion is confirmed by the results obtained on the *Infernet*. Some engineers object to the "direct-flame" type even though it has the advantage of bringing the uptakes and the funnel to the back of the boilers. On the other hand, the "direct-tube" type gave very good results on board the *Château-Rénault*.

In Figs. 197 and 197A, the transverse section is applicable to both types, and the longitudinal section to the "direct-flame" type only.

The two outside rows of tubes form a "tube-wall," thereby protecting the boiler casing, and forming a water-wall around the hot gases.

Some of the various arrangements adopted to direct the current of hot gases deserve notice. The two inner rows of tubes forming the tube-walls, and which constitute the side of the furnace, are so arranged as to touch each other just underneath the upper barrel, and thus form an arch or vault over the fire-grate. Fire-bricks are placed just above where the tubes approach one another to prevent the flames touching the upper drum.

The flames, before reaching the end of their passage along the bank of generating tubes, are deflected down-

FORBAN.

NORMAND BOILER (1894)

Scale 22 mm. = 1 metre.

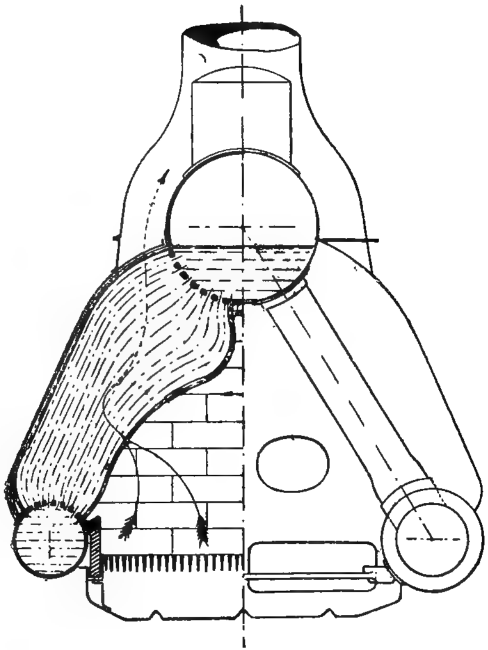


Fig. 197.

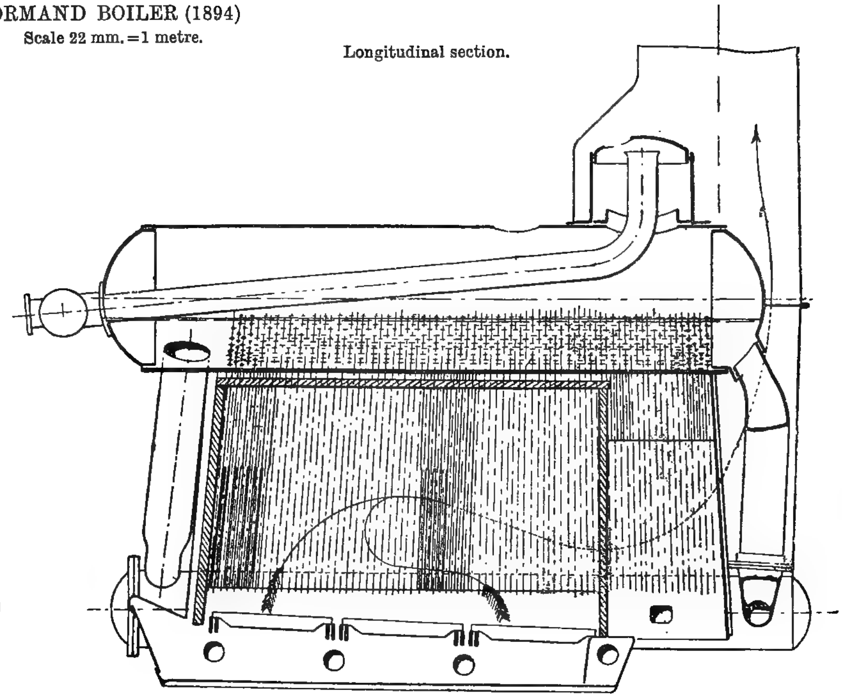


Fig. 197 A.

wards by baffle plates, called by M. Normand "hanging bridges," under which they have to pass before entering the smoke-boxes, instead of escaping directly from the top. In the "direct-flame" type (Fig. 197), these baffles are placed in line with the fire-brick partition forming the back end of the furnace.

The passages in the internal tube-walls, through which the hot gases from the furnace enter the nest of tubes, are formed by leaving spaces, or interstices, for a portion of their height in the two rows of tubes forming the internal wall. Where these spaces are left, the tubes have sometimes been slightly reduced in diameter so as to offer less obstruction to the entry of the gases.

The new boilers made for the *Forban* at the Du Temple works embody the advantages of the "return-flame" boiler of the *Aquilon*, having the funnel at the back of the boiler, and thus avoid any radiation of heat into the stokehold from the uptakes. In this type the gases after returning through the nest of tubes, take a course towards the back of the boiler between a wall of tubes and the casing (see Figs. 198, 198A). This arrangement, which is due to M. Soude, though favourable to the total efficiency, did not improve the efficiency of combustion or diminish the deposits of soot, or effect the suppression of smoke. To effect this the unrestricted path or passage of the gases ought to have been arranged for on the inside next the fire, and not on the outside, so that combustion would have been complete before the flames entered the nest of tubes proper.

Normand boilers are usually fitted with tubes of 1.18 ins. external diameter and .098 in. thick, the tubes forming the tube-wall being increased in thickness to .118 in. Sufficient elasticity is thus procured to avoid any straining of the tubes where they enter the tube-plates. The drums have sufficient thickness where the tubes enter them to allow of their being properly expanded. Where

there are no tubes the thickness of the plate is reduced by planing.

These details show the care taken to ensure satisfactory working and high efficiency. There are still others worthy of note. Thus, openings for the entry of air above the grate are provided both at the front and back. Those at the back are made in the brickwork forming the back or end of the furnace; it is for this reason that the space at the back of the brickwork is kept clear by making the smoke-box of "breeches" shape. The air admitted at the front is first warmed by passing between the front casing of the boiler and the brickwork forming the front end of the furnace. The ashpan is open at both ends, the door at the back being worked from the front of the boiler. The boiler as now constructed has been developed from the earlier types by a series of careful experiments, those made by M. Normand about the year 1894 being especially interesting.

His first boilers were fitted with brass and copper tubes with the object of increasing their durability. The three rows next the fire were of brass and the remainder of copper. These metals, however, proved unsatisfactory. Brass tubes in particular are, owing to the method of manufacture, full of small cracks which pass unnoticed when subjected to external pressure, but render the tubes unfit to stand internal pressure. M. Normand now uses only iron tubes, which he prefers to steel ones. The iron used must be soft iron, which may easily be mistaken for soft 25-ton steel. Some Swedish steels answer the purpose very well both as regards composition and homogeneity.

M. Normand at first found it difficult to provide sufficient heating surface. The great reduction in the lengths of the tubes, following the abandonment of the folds, necessitated an increase in their number, but there was not sufficient room on the top drum to accommodate their upper ends,

FORBAN.
(NEW BOILER, 1901).
Scale 22 mm=1 metre.

Longitudinal section.

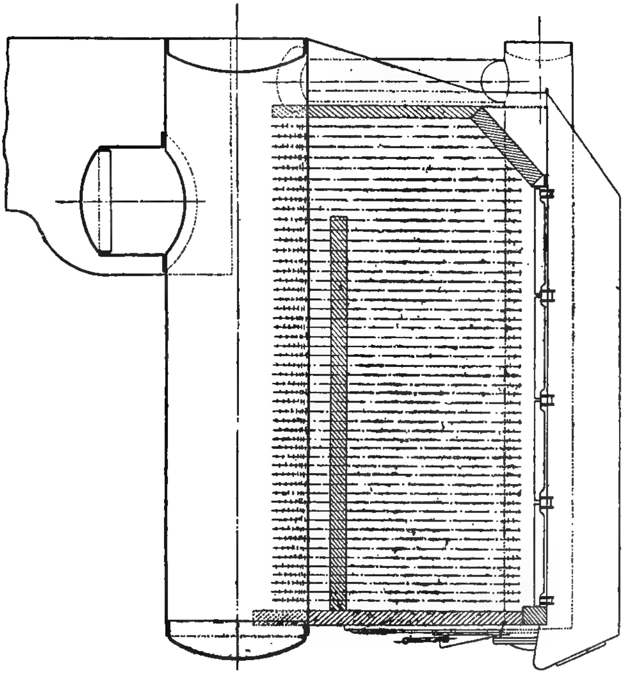


Fig. 198A.

Half section. Half elevation.

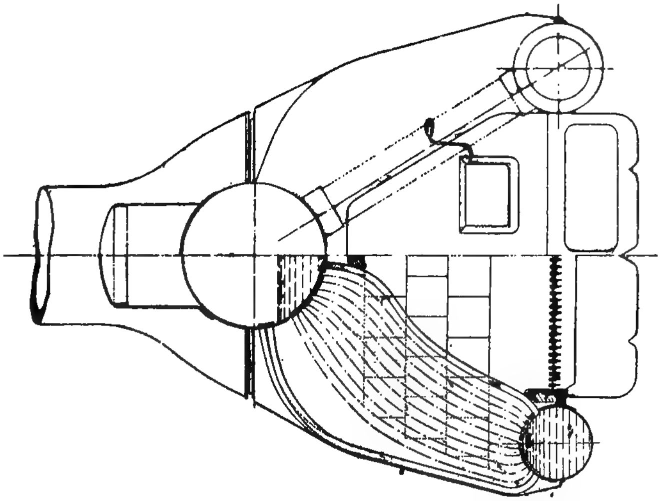


Fig. 198.

which M. Normand considers should be below the water-level, and not above, as in the earlier Thornycroft boiler. The ends of the three outside rows of tubes were, however, above the normal water-level, but without being in any way bent downwards, so as to avoid the formation of air-pockets. He thought it necessary to protect the portions of the tube above the water-level by a baffle plate, but this precaution is perhaps superfluous. The length of the present boilers enables a sufficient number of tubes to be used, all of which enter the upper drum below the water-level.

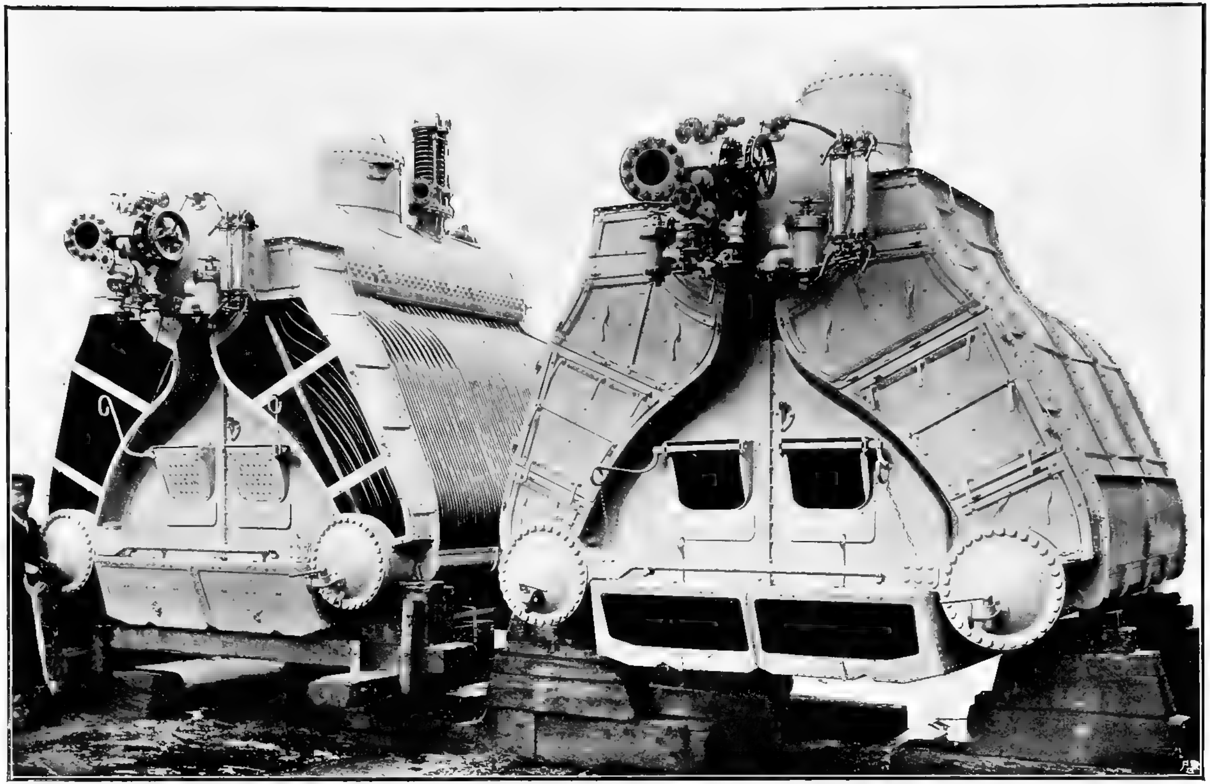
As good examples of M. Normand's boilers, those of the *Forban* and the *Pique* may be cited, their principal particulars being as follows :—

		FORBAN.	PIQUE.
Pressure in boiler	lbs.	44·13	39·8
Weight of water	tons	2314	1810
Weight with fittings, including funnel	tons	1·34	1·18
Thickness of tubes	in.	0·118	0·098 and 0·11
External diameter of tubes	in.	12·2	9·2
Heating surface	sq. ft.	3·12	1·7
Grate area	sq. ft.	225	225

The grate area of 44.13 sq. ft. has only been obtained by making the length 7 ft. 9 ins. Such a length renders the stoking difficult, and good stokers are necessary, although the height of the furnace facilitates throwing the coal to the back of the grate. However this may be, very good results were obtained on trial. While steaming at 31.03 knots, a rate of combustion of 63.9 lbs. of coal per square foot of grate was maintained, and 46.8 horse-power developed per square foot of grate. The results of the trials of the *Forban* are also given in paragraph 40, as well as those of the *Flibustier*, the *Ariel*, the *Cyclone*, and the torpedo-boat destroyers.

Plate III. illustrates a pair of Normand boilers of the

NORMAND BOILERS FOR DESTROYERS OF THE *CYCLONE* TYPE.



[*To face p.* 440.

"Cyclone" type having the following dimensions per boiler :—

Grate area	57·88 sq. ft.
Heating surface . .	2357·4 ,,
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	40·72
Weight of one boiler including all fittings lagging, etc., and casing up to centre of top drum .	12·20 tons
Water	2·75 ,,
Total	14·95 tons

The Du Temple and the Normand boilers on board torpedo-boats have given rise to serious mishaps, nearly always due to the lowering of the water-level, but luckily unaccompanied as a rule by any fatal accidents to the stokehold staff. In the recent accident on Torpedo-boat No. 208, without the stokehold staff being aware of it, a tube burst, and, while the hatch was open, a stoker opened a fire-door, with the result that he was badly burnt by the back rush of the flame, and subsequently died of his injuries.

143 *The Application of Du Temple Type boilers to large ships.—Normand-Sigaudy and Du Temple-Guyot boilers.*—M. Normand having arrived by successive improvements at a type of boiler which, though not final, is undisputably superior to the original Du Temple boiler, considerable advantage should certainly be derived from its more general employment on larger ships. Single- or double-ended boilers might be used according to circumstances, the latter enabling a slight saving in weight, and space occupied, to be effected. The double-ended boiler which M. Normand has introduced in collaboration with M. Sigaudy of the Compagnie des Forges et Chantiers de la Mediteranée (Havre), is composed of two Normand boilers placed back to back, with the barrels common and continuous.

The two types—return-flame and direct-flame—form

two kinds of double-ended boilers as represented by Figs. 199 and 199A, which are taken from the drawings accompanying the application for the patent. These figures are sufficiently clear, and nothing need be added to the descriptions given of the single-ended boilers. In the return-flame type (Fig. 199A), the smoke-boxes are sometimes placed

NORMAND-SIGAUDY BOILERS.

DIRECT-FLAME TYPE.

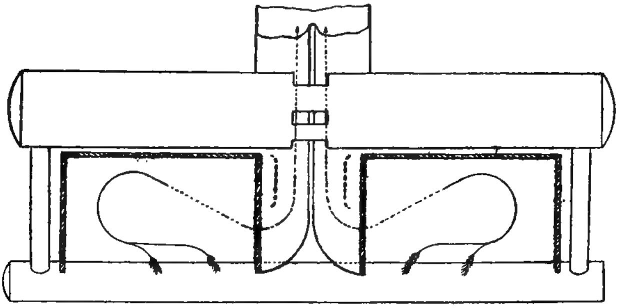


Fig. 199.

RETURN-FLAME TYPE.

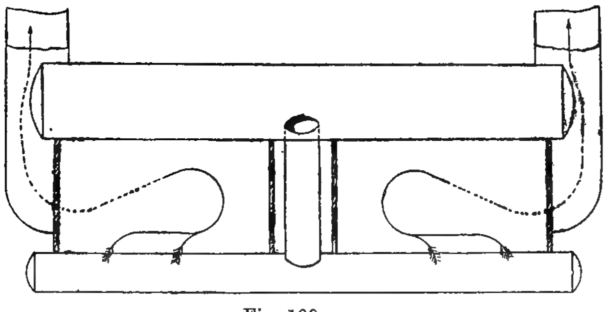


Fig. 199A.

on the front and sometimes on the sides, according to the space available. In the direct-flame type (Fig. 199) the smoke-boxes naturally lead to a common funnel in the centre of the boiler. In both cases a clear space is left between the back ends of the furnaces for the admission of air above the grates.

The only difference due to the mode of coupling the boilers together is in the reduction of the down-take tubes. The direct-flame type has its downtake tubes at the ends, the return-flame has them at the centre between the two furnaces. This difference is caused by the upper reservoir

JEANNE D'ARC.

DU TEMPLE-GUYOT BOILER PROPOSED BUT NOT FITTED.

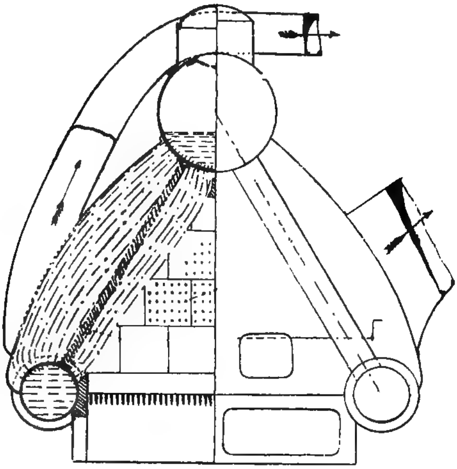


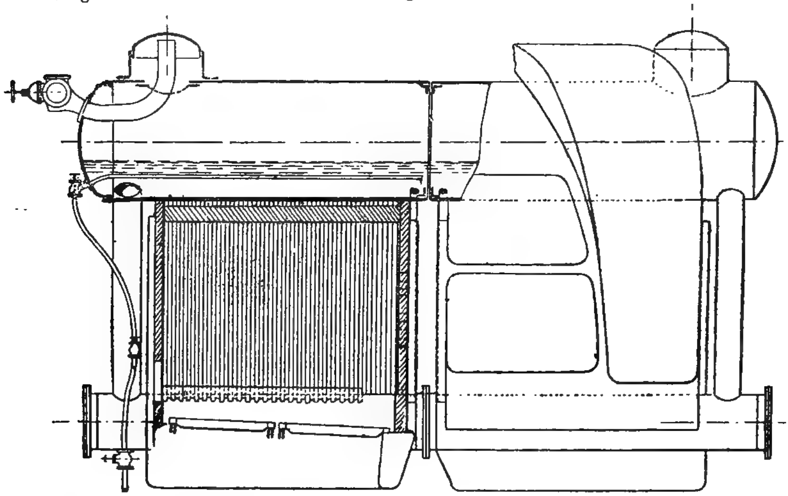
Fig. 200.

			RATIO TO GRATE AREA.
Working pressure	lbs. per sq. in.	242	
Number of boilers		13	
Length of grate		6 ft. 9½ ins. × 2	
Width of grate		7 ft. 5⅝ in.	
Surface of grates	sq. ft.	101·16	
Outside diameter of tubes	in.	1·181	
Inside diameter of tubes	,,	0·984	
Number of tubes		1,994	
Heating surface (dry)	sq. ft.	4617·7	46·646
,, ,, (wetted)	,,	3859·8	38·154
Surface of water-level	,,	60·1	0·593
Free area through ashpans	,,	18·73	0·185
Area of passages for gases between the tubes	,,	28	0·296
Volume of water	cub. ft.	117·9	
,, ,, steam	,,	132	
Approximate weight with grates and accessories	tons.	20·07	
Total weight with water	,,	34·7	

of the direct-flame boiler having a reduced portion at the middle of its length, so as to offer the least possible obstruction to the passage of the gases through the uptakes.

The advantages possessed by double-ended boilers are

Half longitudinal section. Fig. 200A. Half elevation.



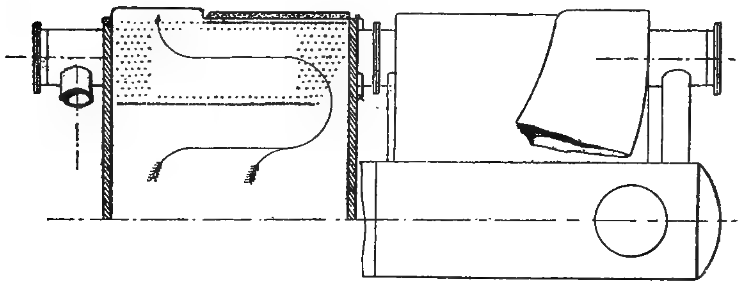


Fig. 200B.

not so great in the case of tubulous as in that of cylindrical boilers, because the saving in weight is much less. On the other hand, their use presents no disadvantages except that in the event of damage to any of the parts under pressure in one half of the boiler, the whole boiler would

BOILERS OF "CHÂTEAU-RÉNAULT."

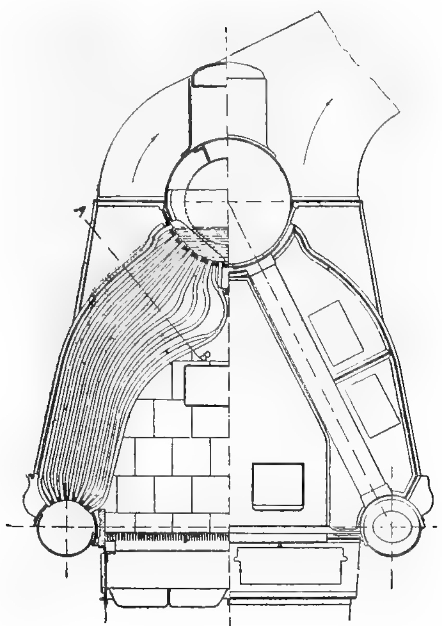


Fig. 201.

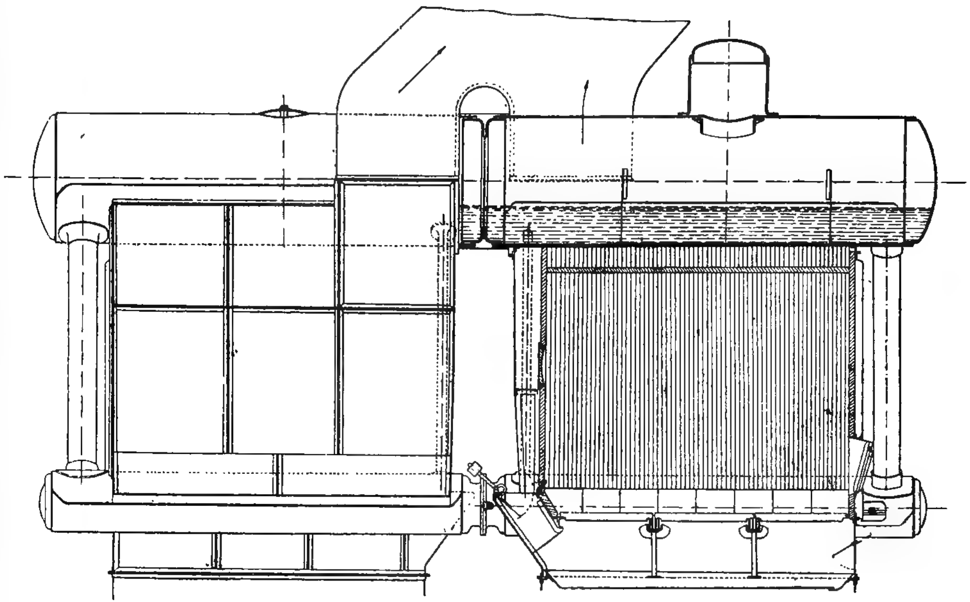


Fig. 201A.

be disabled; both portions of the boiler have in all cases separate uptakes, and may even be worked at different rates of forcing. Precautions should be taken to prevent excessive changes in the water-level, due to the pitching or rolling of the vessel, as the top drums are often over 19 ft. long. Lastly, the successful application of boilers of the Du Temple class to large ships, depends, as in all types of tubulous boilers, on the satisfactory solution of some general problems, such as regularity of feed-supply, etc.

As examples of double-ended boilers may be mentioned those of the Du Temple-Guyot type (Fig. 200), adopted for the *Jeanne d'Arc* at the end of 1895 and constructed at Indret, and the Normand-Sigaudy boilers (Fig. 201A,

Half-section on AB.

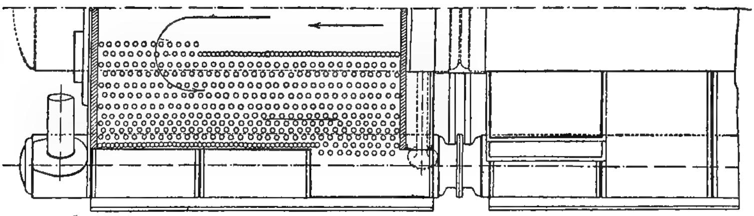


Fig. 201B.

			RATIO TO GRATE AREA
Working pressure	lbs. per sq. ins.	213	
Number of double boilers		12	
Length of grate		7 ft. 6 in.	
Width of grate		4 ft. 1½ in.	
Total grate area	sq. ft.	96·58	
External diameter of tubes	in.	1.417	
Internal diameter of tubes	,,	1·18	
Number of tubes		1744	
Heating surface (dry)	sq. ft.	4587·5	47·51
,, ,, (wet)	,,	4132·5	42·42
Surface of evaporation	,,	63·5	·658
Area through ashpans	,,	20·51	·212
Area of passages through the tubes	,,	29·06	·300
Volume of water	cub. ft.	240[1]	
Volume of steam	,,	152·6	
Approximate weights with grates and accessories	tons	36·9	
Total weight with water	,,	43·6	

201B), adopted in 1896 for the *Château-Rénault*, constructed at Havre.

In the original designs of M. Sigaudy, a difficulty arose in making the bottom reservoirs in one piece, and it was difficult, with bolted collars between them, to fit them on board with the care that was necessary to ensure tightness. On the *Château-Rénault* the bottom collectors were kept separate

JUNCTION OF THE LOWER COLLECTORS.

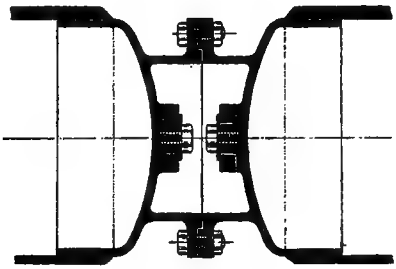


Fig. 202.

for each boiler and bolted up as shown in Fig. 202. Hence, as far as the bottom drums are concerned, the boilers are really simple Normand boilers. On the *Jeanne d'Arc*, the problem was solved by using single-ended boilers only. The boilers of the Du Temple type have undergone certain modifications, when applied to larger vessels, the diameter of the generating tubes being in general slightly increased. For instance, on the *Château-Rénault*, *Montcalm*, and *Jules Ferry*, they were 1.416 ins. in diameter and .118 ins. thick, which allowed for sufficient flexibility. The sills of the fire-doors have been lowered so as to permit of the fires being thoroughly cleaned. This is not such an important matter on torpedo-boats and the like, but on large boats, such as cruisers, it is an absolute necessity.

Normand boilers have been thoroughly tested in service on the two cruisers *D'Estrées* and *Infernet* with good

results. The figures obtained on the trial trips are given below :

	D'Estrées.		*Infernet.*	
Grate area in sq. ft.	391	195·5	391	97·75
Heating surface in sq. ft.	20,100	10,050	20,100	5025
Lbs. of coal per sq. ft. of grate	45·1	13·31	41·5	12·34
H.-P. developed	8676	1675	8510	912
Lbs. of coal per H.-P. hour	2·012	1·421	1·886	1·321

The boilers of these boats were built at Creusot. On board the *Château-Rénault* the results have been satisfactory up till now. The mean results of evaporative trials conducted at Havre on a single boiler were as follows:

Air pressure in ins. of water	0	·39	·59 and ·78	·98
Lbs. of coal per sq. ft. of grate	16·38	24·58	32·77	36·87
Water evaporated per lb. of coal	9·26	8·88	7·39	8·06

These results may be compared with those obtained with a single boiler for the *Jeanne d'Arc.*

Air pressure in ins. of water	0	·59 and ·906	·866	1·18 and 1·575
Lbs. of coal per sq. ft. of grate	14·34	28·70	36·87	40·96
Water evaporated per lb. of coal	9·01	8·87	8·18	8·13

Lastly, the results obtained by M. Fromonot at Indret on the boilers of the *Jurien-de-la-Gravière* permit the output of a good Du Temple-Guyot boiler, under the conditions obtaining on board, to be determined. The temperature of the feed water was 50° Fahr. and the pressure 255 lbs.

Lbs. of coal per sq. ft. of Grate.	Water evaporated per lb. of Coal.	Efficiency per cent.
	Lbs.	
16·39	9·20	67·5
22·53	9·10	66·7
38·92	8·68	63·6
46·09	8·50	62·3

The calorific value of the coal was calculated for determining the efficiency, and was 16,200 thermal units. Baffle-plates were fitted to the boilers used on these trials. At Indret the casings are so constructed that these baffle-plates can be easily inspected and renewed, and they are particularly useful on Du Temple-Guyot boilers of large size.

144. *Rapid Introduction of Boilers of the Du Temple Type.* —The satisfactory results obtained in France with the Du Temple boilers on board torpedo-boats lead to their rapid introduction in other countries. In England, where perhaps some reminiscences of the Goldsworth-Gurney boiler,* patented in 1827, may have survived, Mr Thornycroft anticipated M. Normand, and was closely followed by Mr Yarrow, and a number of other engineers again followed them. When the British Admiralty in 1894-5, who up till that time had not had many torpedo-boats, decided to order a hundred torpedo-boat destroyers, the construction of this type of boiler received a great impetus, and the number of different types brought out was considerable. The Admiralty fitted the Normand type of boiler to the *Pelorus* with satisfactory results. On the larger class of ships, for the next four or five years, the Belleville boiler was almost exclusively fitted, but the feeling against the small tube boilers now appears to have diminished, and they have been fitted in fairly large numbers on the *Proserpine* and the *Bellona* types.

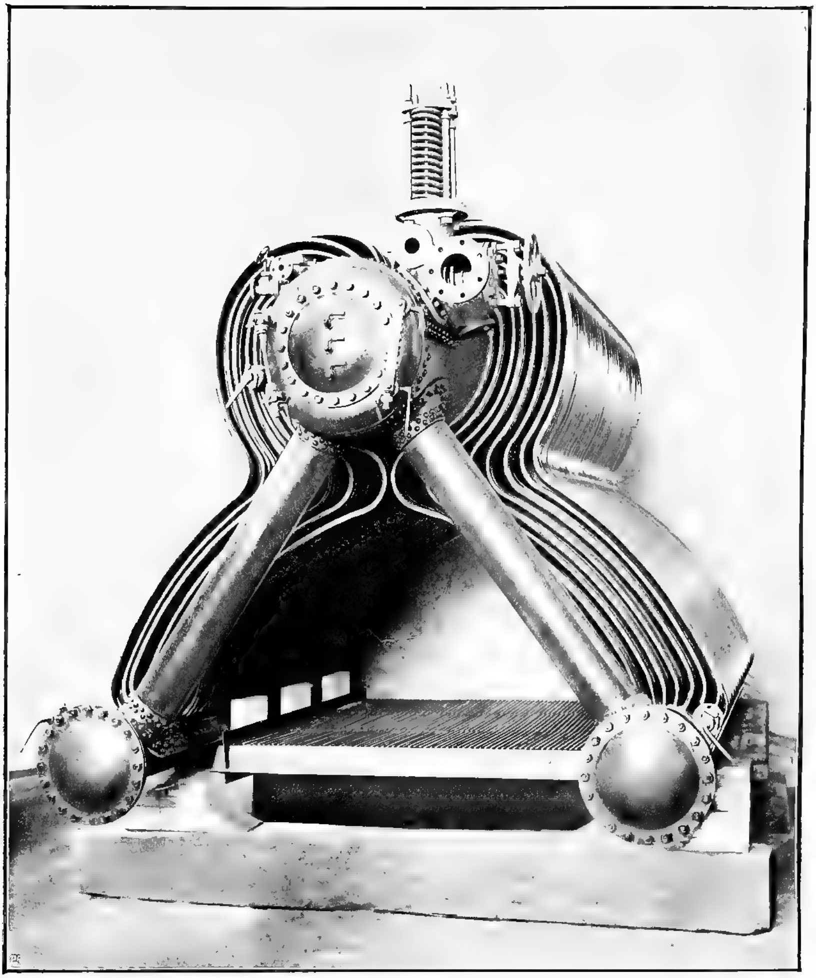
The Naval Authorities in Washington have been slow in creating a fleet of torpedo-boats, and hence the development of this class of boiler has been slow. They are now making up for lost time, and all the American torpedo-boats have been fitted with boilers with accelerated circulation; their use has even extended, as in England, to large vessels. In Germany, Schichau, who was for a long time

* *See* Seaton, "Manual of Marine Engineering," p. 398 of 15th Edition 1904. *See* also "Water Tube Boilers," by the Editor, p. 6.

faithful to the locomotive boiler, has now adopted boilers of the Du Temple or Normand type, and has further introduced them into other navies, such as the Italian Navy, for which they were in the habit of building. The German Imperial Navy has not been backward in following the general movement and has fitted this type of boiler on all their recent boats, whether cruisers or battleships. The number of Schulz boilers fitted to this class of boat far exceeds what was done in France six years ago with the Du Temple, Normand, or Guyot boilers for the *Jeanne d'Arc*, *Jurien*, and *d'Estrées*. The Dutch Navy has during the last few years adopted one type of boiler with accelerated circulation, to the exclusion of all others, thus realising the very desirable object of having all the boilers of one type. Careful investigation, assisted by the systematic experiments which have been conducted for some time past in the private yards of England and Scotland by Messrs Yarrow, Thornycroft, Watkinson, Weir, and others, have somewhat reduced the lead secured by the French about 1895. New types are continually being brought out embodying sometimes real progress. The complete history of boilers with accelerated circulation, attributing to each inventor the improvement introduced by him, would be as difficult as the history of the Belleville or Niclausse boiler is simple. The results achieved are rarely obtainable with any completeness, and have had mainly to be extracted from English periodicals.

145. *Early Types of Thornycroft Boiler.*—This boiler, introduced in 1885, is well known in the French Navy, having been fitted to several torpedo-boats, the *Coureur* (built by Messrs John I. Thornycroft & Co.), the *Véloce*, *Grondeur*, *Eclair*, *Kabyle*, *Orage*, torpedo-boats Nos. 164, 165, 166, and the gunboats *Argus* and *Viligante*. The characteristic feature of the early type consists in the form given to the generating tubes (Fig. 203). These are very

EARLY TYPE THORNYCROFT BOILER FOR THE
VÉLOCE AND *GRONDEUR*.



To face p. 451.

long; their upper ends are connected to the upper part of the steam drum or separator above the water-level, and the tubes are curved in such a way as to form a complete arch over the fire-grate.

EARLY THORNYCROFT BOILER (SPEEDY TYPE).

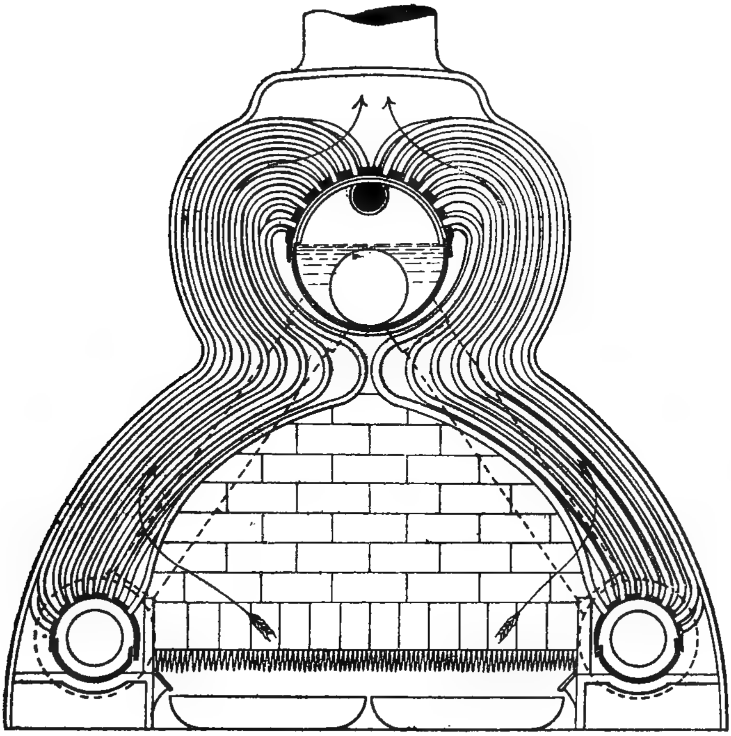


Fig. 203.

Plate IV. illustrates a boiler, with casing removed, built under the supervision of the Editor for the *Véloce* and *Grondeur* at Havre, having the following dimensions :—

Tube Surface	2,400 sq. ft.
Grate Area	38 ,,
Weight, complete with casing, dry .	9·0 tons
Water	1·4 ,,
Total .	10·4 tons
I.H.P. with T.S.E. engines . .	800

Tube-walls are formed on the insides and outsides of each bank of tubes, leaving long triangular spaces at the bottoms of the internal, and at the tops of the external, tube-walls for the free passage of the hot gases. The gases thus follow the course of the tubes throughout the whole of their length.

This arrangement gives a very large heating surface, varying from 52 to 72 times the grate area. It may be pointed out that permitting the gases to follow the direction of the tubes is not so efficient as forcing them to cross the tubes; but in adopting, and retaining it, Sir John Thornycroft had more particularly in view a mode of circulation which he regards as very advantageous.

From observations made with a separator provided with glass sight-holes, it appears that, with tubes delivering above the water-level, the circulation, though it may be intermittent, is always in one direction.

With tubes having their upper ends submerged, the movement is, on the contrary, oscillatory, the escape of a puff of steam being followed by the entrance of water to fill the space left vacant. The result of this is that in the Thornycroft boiler there is a marked reduction in the resistance offered to the circulation, which more than compensates for the slight loss of head, equal to the height of the orifice of each tube above the water-level. From approximate measurements of the velocity of the water in the downtakes Sir John Thornycroft showed experimentally that the weight of water in circulation in his boiler is equal to 104 times the weight of that evaporated, whilst with submerged tubes it was only 50 times that weight. However this may be, there can be no doubt that the movement is, without exception, in an upward direction in all the tubes of a Thornycroft boiler, and that the water is returned entirely by the large external downtakes, the cycle being irreversible.

Sir John Thornycroft considered that the above-water discharge reduces the risk of priming. On this point experience has not yet enabled any exact conclusions to be arrived at. The Du Temple and Normand boilers prime but little. On the other hand, the Thornycroft boilers of the *Speedy* primed during trial; but this priming was probably largely due to the bad quality of the water used for "make-up." The mixture of water and steam issuing from the generating tubes is projected against baffles so arranged as to prevent the water being carried along by the steam, in a somewhat similar manner to the Belleville separators.

The fear of overheating the portions of the generating tubes above the water-level has given rise to some prejudice against the Thornycroft boiler. This fear is unfounded, as, while at work, there is water throughout the whole length of the tubes. In an accident on the *Coureur* the upper portions of all the tubes were melted; but there had evidently been a failure in the feed supply. This was also the case on the *Averne*, where the lower portions of the tubes of a Du Temple boiler were also burnt out. A better founded objection is the impossibility of completely filling the tubes with an alkaline solution in order to prevent internal corrosion when the boiler is laid up.

The tubes are of solid drawn steel and are merely expanded in the tube-plates. They are galvanized in order to protect them from corrosion. The zinc soon disappears in service; on the *Speedy* it was remarked that its disappearance coincides with the presence of an explosive mixture inside the empty boiler, but no satisfactory explanation of this phenomenon is yet forthcoming.

Galvanizing has the advantage of rendering very apparent the slightest defects in the steel, and thus facilitating the examination of the material; this of itself is a sufficient reason for the adoption of the process.

The lower ends of the tubes were sometimes reduced

in diameter so as to cut away as little as possible the plates forming the lower barrels.

The type of boiler represented by Fig. 203 has been fitted to some vessels of moderate size, such as the *Speedy*, a boat of 800 tons, which carries eight of these boilers. Experience gained on this ship has brought into prominence the advantages of automatic feed regulators where several boilers are coupled together. The Thornycroft feed-water regulator has a counterpoise, being in this respect similar to the Belleville, but it is entirely contained inside the steam-drum, as described in paragraph 188.

The leading particulars of the boilers of the *Coureur* and the *Speedy* are as follows:—

	Coureur.	*Speedy.*
Number of boilers	2	8
Total grate area . . . . sq. ft.	76·2	204
Total heating surface . . . „	4,026	14,720
Ratio of heating to grate surface	52·8	72·1
Weight of boilers (dry) . . . . tons	17·37	79·7
„ „ water in boilers . . . „	3·54	12·8
Total weight . . . . „	20·9	92·5
Total weight per sq. ft. of grate . . „	·274	·453
Total maximum power obtained on trial	1,507	4,500
„ „ „ „ „ per sq. ft. of grate	19·8	22·2

The greatest power developed during a run on the *Coureur* was 22.1 horse-power per square foot of grate area, with a combustion of 69.8 lbs. per square foot, and a consumption of 3.16 lbs. per horse-power. Under natural draught the *Coureur* consumes only 1.56 lbs. of coal per horse-power. On the French torpedo-boats, Nos. 164, 165, 166, the rate of combustion is not allowed to exceed 51 lbs. per square foot of grate; there is, however, nothing to show that this rate may not be exceeded without danger.

In 1892 Sir John Thornycroft devised a new form of boiler adapted for arrangement into groups on ships having

several boilers. The first ships fitted with this new boiler were the two small Danish cruisers, the *Geiser*, 1,260 tons, and the *Skjold*, of 2,115 tons. They have also been fitted to about 38 English torpedo-boat destroyers, *Daring*, *Desperate*, etc.; the third-class cruisers, *Proserpine*, *Perseus*, *Prometheus*, *Psyche*, *Pandora*, *Pioneer*, each of 7,000 I.H.P.; the *Barham* and *Bellona*, each of 6,000 I.H.P. They have also been fitted to large boats in the Austrian and German Navies.

The following data are obtained from the official trials of recent torpedo-boat destroyers fitted with Thornycroft boilers:—

Boat	*Daring.*	*Boxer.*	*Mallard.*	*Desperate.*	*Foam.*	*Ardent.*	*Fame.*
Duration of trial hours	3	3	3	3	3	12	12
Number of boilers	3	3	3	3	3	2 in use	2 in use
Tube surface sq. ft. total	8,892	9,285	12,060	12,060	12,060	6,190	8,040
Grate area sq. ft. „	189	189	196	196	196	126	84*
Indicated horse-power	4,408	4,543	5,746	5,796	5,846	499	445
Speed knots	27·7	29·17	30·2	30·03	30·1	13	12·7
Indicated horse-power per sq. ft. of grate	23·3	24	29·3	29·6	29·8	3·96	5·3
Indicated horse-power per ton of boilers complete with all mountings and fittings and including water	96½	97	99⅔	107½	106		
Coal per horse-power per hour lbs.	..	..	2·08	..	2·205	1·53	1·66

* Length of grates reduced for this trial.

The arrangement shown in Fig. 204 has been suggested, in a paper read before the Institution of Naval Architects, for grouping the Thornycroft boiler on large vessels, but it has never actually been carried out in practice. Each group is composed of separate and distinct elements contained in a common casing. Each element includes two drums only, placed vertically one over the other, and connected by two banks of generating tubes. The down-

takes are distributed over the length of the boiler in the space between the two sets of generating tubes, an arrangement which permits of an excellent circulation.

In this design each element is heated by two furnaces, and each furnace serves for two half elements. The grates at the ends of the group (which only serve one half element) are smaller than the rest, and the outside of the furnace is formed by a tube-wall, the tubes of which are connected at their lower ends to a small barrel or wing-tube.

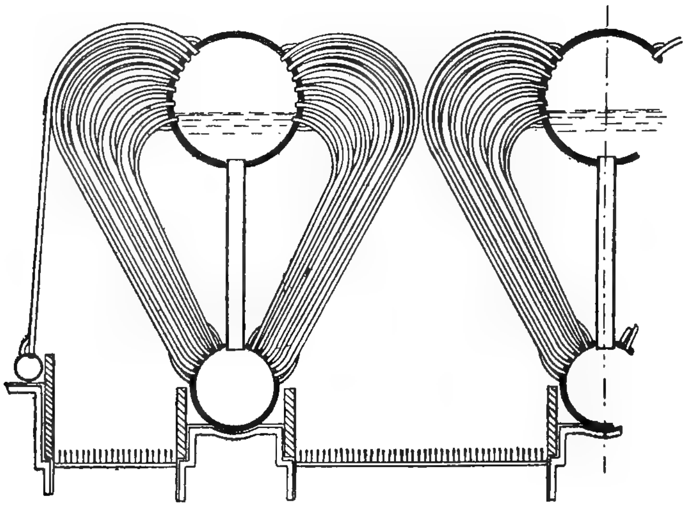


Fig. 204.

This arrangement for grouping the *Daring* type of boiler shows an economy of weight over the *Speedy* type.

The disadvantages of a boiler of several elements are that in case of accident to one of the elements, such as the bursting of a tube, the whole group is filled with steam, all the furnaces being in communication. It would then, presumably, be necessary to draw the whole of the fires in the group in order to replace the defective tube—an operation at times of rather long duration.

The three boilers of the *Daring* have a total grate area of 189 sq. ft. The heating surface is forty-two times the grate area. On a full-speed trial, when 29.268 knots were recorded, the air-pressure in the stokeholds was 3.15 ins. and the horse-power 23.5 per sq. ft. of grate. The boilers were found to work satisfactorily.

The *Desperate*, which has likewise three boilers, has attained a speed of 30.006 knots, while developing 5,800 horse-power. At this rate of forcing, the consumption of coal per horse-power was 2.48 lbs.

A boiler of the *Daring* type was carefully tested in 1888 by Dr (now Sir Alex.) Kennedy; complete results of these tests are given in the "Proceedings of the Institution of Civil Engineers," Vol. XCIX.

Under conditions very nearly approaching those of practice, one of the *Bellona's* boilers was tested on shore in 1897 by the Admiralty, and gave the following results:—

Grate area	38·5 sq. ft.
Heating surface	2104 sq. ft.
Ratio H.S. to G.S.	54·65
Weight of boiler dry	11·00 tons.
Weight of water	1·15
Total weight	12·15
Weight per sq. ft. of grate	·315 tons.

Duration of trial	2 hours	5 hours	4 hours
Coal per sq. ft. of grate per hour (lbs.)	24·21	31·25	47·6
Absolute steam pressure lbs. sq. in.	201·15	201·75	197·25
Temperature of feed	39·10° F.	38·61° F.	38·7° F.
Temperature in funnel	482° F.	514° F.	653° F.
Water evaporated per lb. coal (lbs.)	8·75	7·96	7·23
Water evaporated per lb. of coal from and at 212° F.	10·79	9·82	8·90

There have been one or two bad accidents due to the blowing out of the tubes from the tube-plates—one on the *Ariel* in 1898, and one on the *Daring* in 1901—showing that there is no greater immunity from accident in this type of boiler than with other similar types; but in view

of the large number of boilers in service, the results on the whole must be considered satisfactory. There are more than 40 torpedo-boat destroyers in the British Navy fitted with this type of boiler, and the number of boilers fitted in other navies, especially in that of the United States of America, is very considerable.

The advantages to be derived from making the generating tubes discharge above the water-level has always been contested. Mr Watkinson in particular has made tests on this subject by testing two similar models, one of the Thornycroft and the other of the Normand type. The models had 12.9 sq. ft. of heating surface and evaporated 10.8 lbs. per sq. ft. of H.S. per hour.

These tests showed that the circulation in the Thornycroft boiler was nothing like double that of the Normand boiler. The results proved that once the circulation was thoroughly established, it was much the same in both types. The great objection to the early Thornycroft type lay in the fact that when the boilers were laid up it was impossible to fill them entirely with an alkaline solution. This led Sir John Thornycroft to adopt the drowned generating tubes described in paragraph 147.

Several others appear to have copied Sir John Thornycroft in using unsubmerged tubes.

146. *Early Types of Schulz Boiler, Mosher Boiler, and Symon-House Boiler.*—Among those who have followed Mr, now Sir John, Thornycroft in the use of unsubmerged tubes delivering above the water-level, one of the principal is Mr Schulz, of the *Germania* shipbuilding yard. This type of boiler was adopted by the firm of Schichau when they gave up the use of locomotive boilers. The early form of Schulz boiler is very similar to the *Daring* type. Instead of two nests of tubes, the small side-drums have five rows of tubes forming two tube-walls with a row of tubes in

the middle. The diameter of the side-drums have been slightly increased over those of the *Daring* type. These boilers have been fitted on the *Dardo* and *Lampo* of the Italian Navy.

The Mosher boiler, of American origin, is represented by Fig. 205, and somewhat resembles the *Daring* type,

MOSHER BOILER.

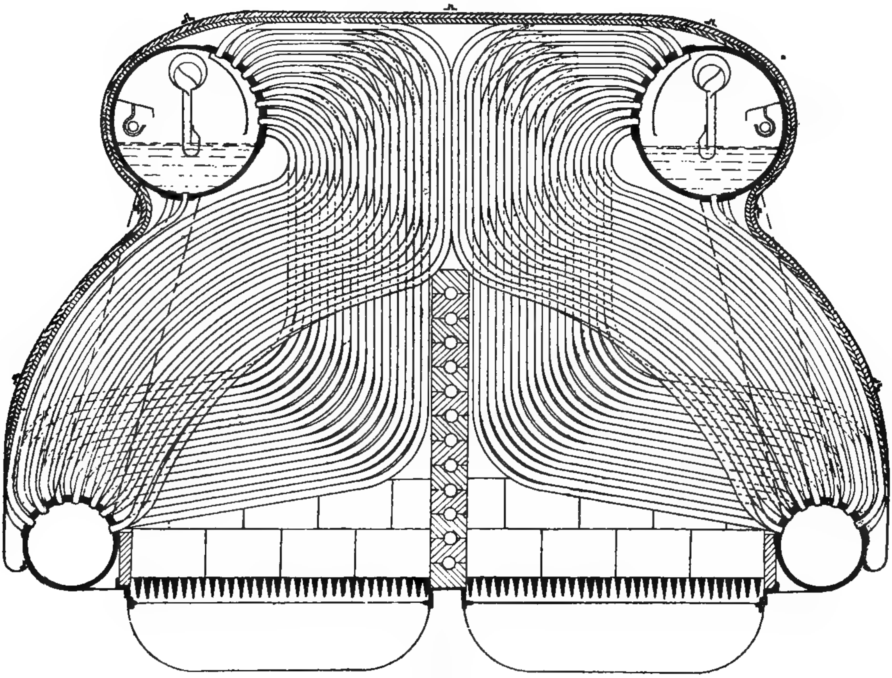


Fig. 205.

but with this difference, that there is one grate for two elements instead of two grates for one element. In case of accident to one of the elements the other can be kept at work, but at the expense of burning the tubes of the first; this is a point of some importance in boats having only one boiler.

The ends of the furnace are formed by a tube-wall, as may be seen in the figure.

The Mosher boiler has been fitted to several yachts and to the second-class torpedo-boat carried by the ill-fated battleship *Maine*. At the Chicago conference the inventor gave the following as the result of an eight-hours'

MOSHER BOILER (LATEST TYPE).

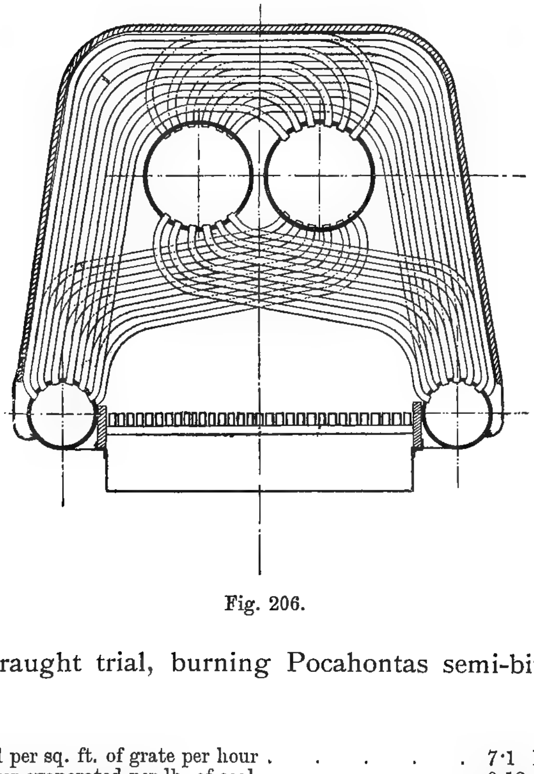


Fig. 206.

natural draught trial, burning Pocahontas semi-bituminous coal.

Coal per sq. ft. of grate per hour	7·1 lbs.
Water evaporated per lb. of coal	9·12 ,,
Air supplied per lb. of coal	304 cub. ft.
Temperature of gases at base of funnel	442° Fahr.
Draught at base of funnel	3 in.
Wetness of steam as measured by calorimeter	1·5 per cent.
Percentage of ashes	7 ,,
Quantity of water evaporated in the ashpans during the whole trial	99·2 lbs.

The principal dimensions of the boiler were:—

Grate area	33 sq. ft.
Heating surface	1,108 ,,
Ratio of grate to heating surface	33·6
Load on safety valves	185 lbs. per sq. in.

Particulars of the heat losses in this boiler have previously been given in paragraph 67.

SYMON-HOUSE BOILER.

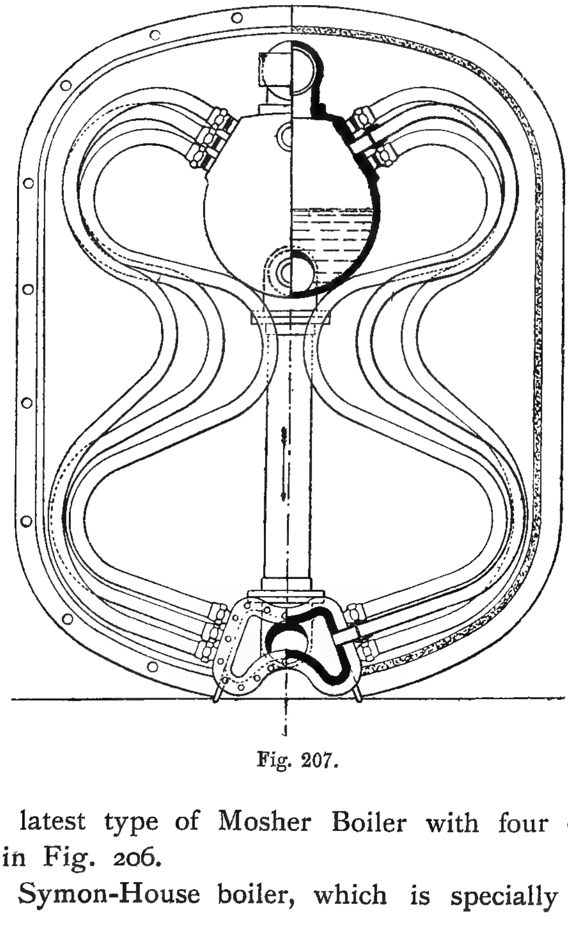


Fig. 207.

The latest type of Mosher Boiler with four drums is shown in Fig. 206.

The Symon-House boiler, which is specially intended

for use with petroleum fuel on small boats and launches, is very similar to one of the elements of a *Daring* type boiler, with the furnace placed between the two banks of tubes, instead of being outside. The flames pass three times over the tubes, which are bent to a double S shape. The particular form given to the bottom reservoir, shown in Fig. 207, is for the purpose of accommodating the propeller shaft, the engine being forward of the boiler.

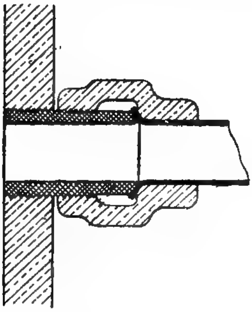


Fig. 207A.

The tubes are of copper, and are attached to the reservoir through the medium of Delta metal nipples screwed into the walls of the latter, as shown in Fig. 207A.

The joint faces are conical and held tight by a nut. Owing to this form of connection the tubes can be very quickly attached or detached ; the shape of the bottom chamber would make it difficult to use the ordinary expanded joint.

The weight of a Symon-House boiler suitable for a 20 horse-power engine is—

Without water or mountings	238 lbs.
Without water, but with mountings	300 ,,
With water and mountings . . .	337 ,,

being an average weight of 18 lbs. per horse-power.

147. *New Type of Thornycroft and Schulz Boilers.*—The latest type of Thornycroft boiler resembles in general arrangement the *Daring* type, but the non-submerged tubes, the characteristic feature of the early boilers, have quite disappeared. There are two furnaces, three bottom drums, and one large top one, and three nests of tubes as shown in Fig. 208. The central nest of tubes is divided in two by a space, which is not traversed by the flames, and here the down-

THORNYCROFT BOILER—IMPROVED DARING TYPE.

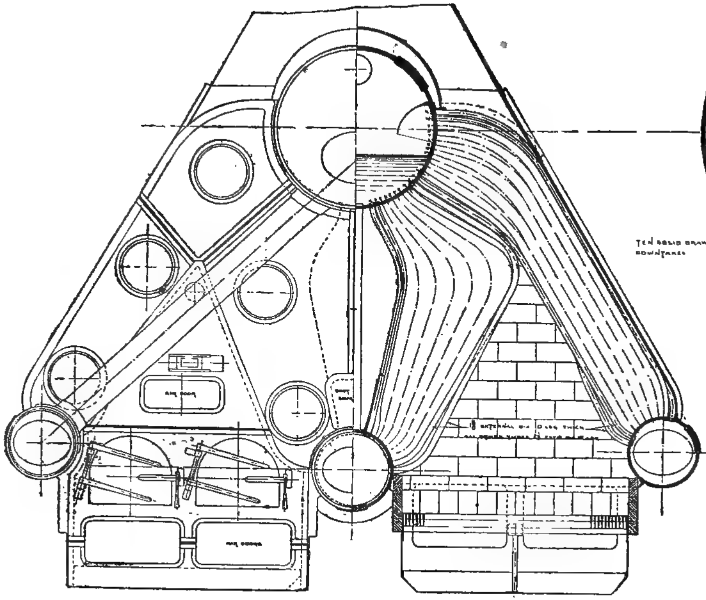


Fig. 208A.

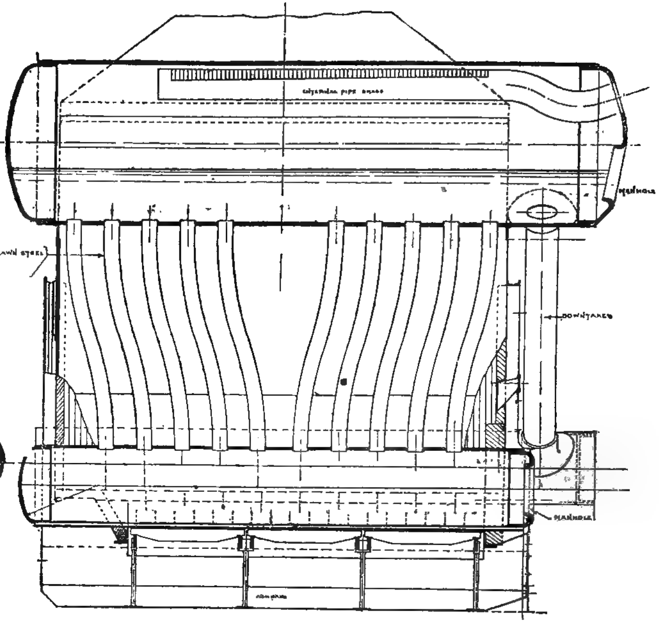


Fig. 208.

comers are situated. The two side drums whose diameter has greatly increased over those in the early types are supplied by a large down-comer on the front, as in the Du Temple, Normand, and other types of boilers. All the tubes from the central nest and most of those from the side nests deliver below the water-level. The course of the gases is indicated by arrows in Fig. 208.

The new type of Thornycroft boiler has again been closely followed by Mr Schulz, and is shown in Fig. 209. It differs

THORNYCROFT-SCHULZ BOILER.

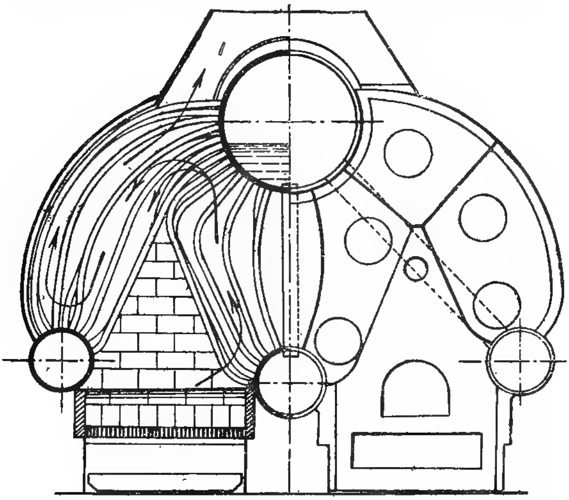
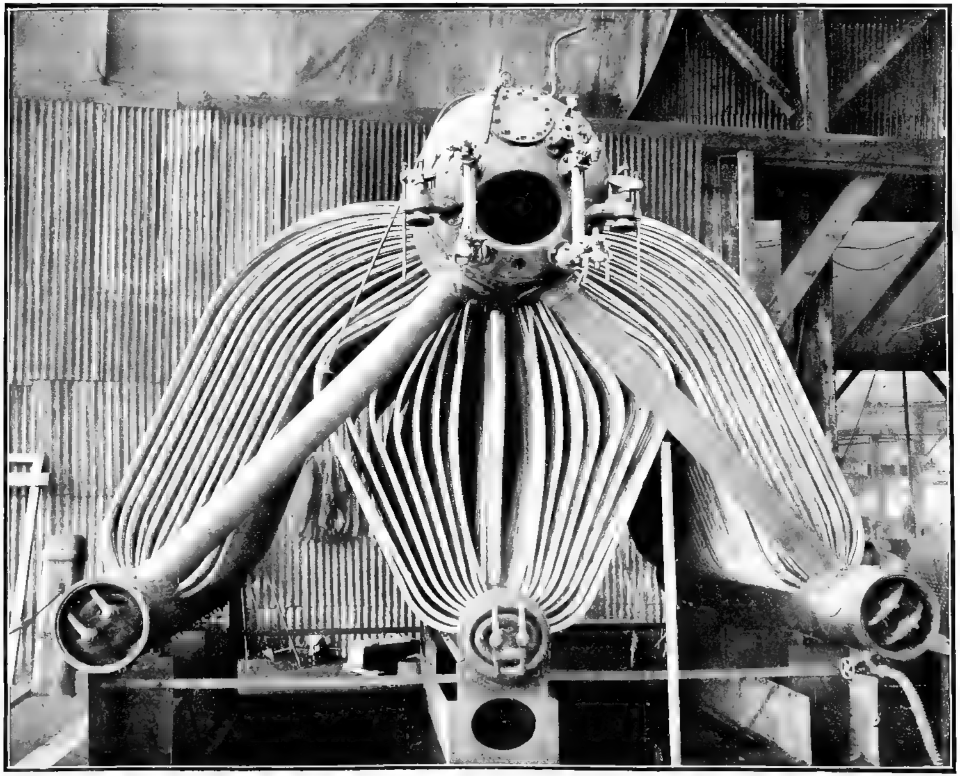


Fig. 209.

slightly from the new Thornycroft type in the side nests of tubes; the flames first pass through half the central nest, and then twice through the side nest as indicated by the arrows. This type of boiler is now known under the name of Schulz-Thornycroft or Thornycroft-Schulz. When it was decided to adopt tubulous boilers in the German Navy, in the case of battleships, for one-third of the total boiler power, and in the case of cruisers and the smaller classes of ships for the whole of their power, the largest share fell to the Thornycroft-

THORNYCROFT BOILER, *DARING* TYPE, FOR $25\frac{1}{2}$-KNOT DESTROYER.



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Schulz boiler working in conjunction with Belleville, Niclausse, and Dürr boilers. The three types of Thornycroft, Schulz, and Thornycroft-Schulz boilers have been fitted on the four cruisers of the *Kaiser* class, five of the *Wittelsbach* class, on the *Aegir* and six coast defence vessels of the *Beowulf* class, on a 20,000 H.-P. cruiser, one of 11,000 H.-P., and ten from 7,000-8,000 H.-P. They are already in service on the cruisers *Ariadne*, *Niobe*, *Nymph*, and on the gunboats of the *Iltis* class. Probably all the torpedo-boats and torpedo destroyers built by Schichau have the new type of Schulz boiler. In the British Navy a number of the new type of Thornycroft boiler have been installed on a vessel of 18,000 H.-P., on several of 7,000 H.-P., and on many smaller boats. This type of boiler is to be found in the United States Navy on the cruisers *Ohio*, *Missouri*, on the monitor *Arkansas*, on about sixteen torpedo-boat destroyers, and on ten torpedo-boats; in the Russian Navy on the *Askold* and the *Novik*; in Spain on the *Estramadura*; in Denmark on the *Herluf-Trolle*, besides in the Navies of numbers of small countries.

Plate V. illustrates a Daring type Thornycroft boiler (with casing removed), and having the following dimensions:—

Tube Surface	4,040 sq. ft.
Grate Area	67 ,,
Weight, dry .	17·5 tons
Water	3·2 ,,
Total .	20·7 tons
I.H.P.	1,875

In July 1901 a bad accident occurred on one of the boilers of the *Ariadne*, in the lateral nest of tubes at the upper tube-plate of the central drum. Thirty-nine tubes were blown completely out of the tube-plate, and twenty-six nearly so, and five were forced inwards. There was a violent escape of steam and six men were injured, two seriously. This

was the first accident on board a big vessel with a moderate rate of combustion, and is the first accident of this gravity since the introduction of the Du Temple boiler, and shows that the inventor's screwed joints were not without their purpose. The cause of the accident on the *Ariadne* has not been made public. If there was no shortage of water, then there must have been either unequal expansion or the tubes had not been properly expanded. The pressure was only 210 lbs. The diameter of the generating tubes on the Schulz boiler is from 1.378 to 1.575 ins., the thickness is .138 in., which makes them stiffer than usual. It is not clear to which type of Schulz boiler that of the *Ariadne* belongs. Another accident occurred recently on one of the boilers of the *Aegir*, where a tube burst, injuring four stokers.

148. *Weir Boiler.* — The Weir boiler utilises more efficiently than either the Normand or the Guyot boilers, and even more effectively than the Scotch boiler itself, the horizontal course of the gases. The furnace is formed by a complete arch of tubes interspersed with fire-bricks until the bridge is reached. The flames return from thence immediately above the tubes forming the arch in a kind of secondary combustion-chamber, and then enter the nest of tubes at the bottom (see Figs. 210 and 210A).

In order to profit by the favourable conditions for complete combustion thus obtained, large air inlets controlled by doors are fixed at the back of the bridge. When these are opened there is an entire absence of smoke. After a month's consecutive trial on Messrs Weirs' shop boiler there was only a very slight deposit of soot on the tubes. The draught was good, but the class of coal used during this period was poor. The entire absence of smoke must no doubt necessitate an excess of air and a consequent reduction in heat efficiency. The efficiency, however, is very satisfactory, as indicated

WEIR BOILER.

Fig. 210A.

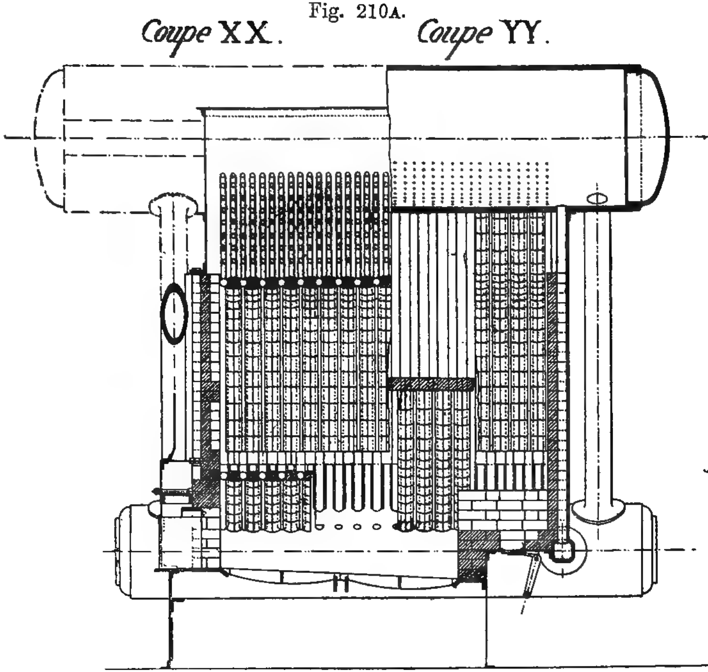
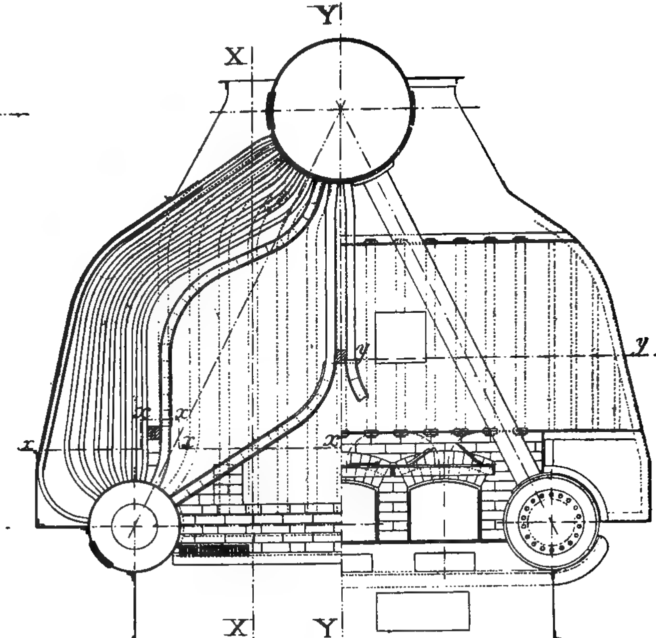


Fig. 210.



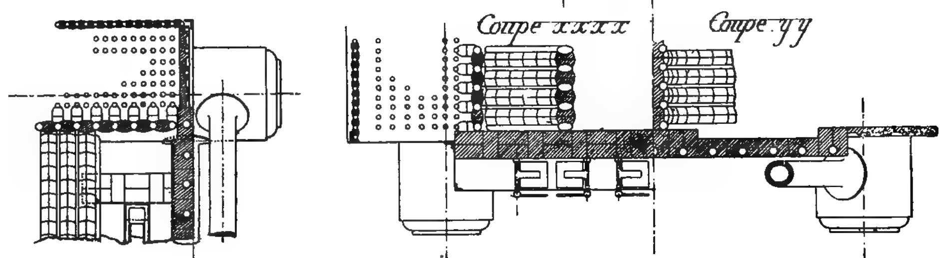


Fig. 210B.

by the following results of tests made on the boiler mentioned above.

Nature of draught	Forced	Natural
Calorific value per lb. of coal (B.T.U.)	12,935	12,935
Lbs. of water evaporated per lb. of coal	7·76	9·36
Quantity of heat per lb. of steam	1133	1107
Heat utilised per lb. of coal	8750	10361
Efficiency of boiler per cent.	67·65	80·10

The principal dimensions of the boiler are as follows :—

Grate area	48·75 sq. ft.
Heating surface	2189 sq. ft.
Ratio	45

Kind of draught	Forced	Natural
Duration of trial	3 hours	4 hours
Draught at base of funnel in ins. of water	3·19	0·591
,, in the combustion-chamber	2·127	0·461
,, in the furnace	0·866	0·244
Lbs. of coal per sq. ft. of grate	62·17	29·0
Mean thickness of fires	12·0 ins.	12·0 ins.
Proportion of slag per cent.	6·70	7·94
,, ash ,,	2·06	1·98

The amount of draught is accounted for by the high shop chimney, and the thickness of the fire justifies the large admission of air over the grate. Mr Weir has experimented on different designs, and the figures given above do not refer to the boiler shown in Fig. 210, and were carried out on a boiler with slightly less heating surface than with that illustrated, which has a ratio of $\frac{HS}{GS}$ of 50.2.

The bottom drums are of fairly large diameter, namely, 2 ft. 3 ins. The generating tubes are of two sizes—2½ ins. external diameter for those forming the arch of the furnace, and 1½ ins. for the others. The baffles are not made by tube-walls, but are of fire-brick fitted in between the tubes. The back and front of the boiler are composed of masonry through which pass vertical tubes; those at the front supply heated air to the furnace. This forms a very happy arrangement, but brings up the weight of the boiler shown in Fig.

210 to 29.8 tons, of which 7.36 is for fire-brick, but without water, uptake, funnel, or spare gear, etc. With 6.06 tons of water it makes a total of 35.86 tons or 0.725 tons per square foot of grate, a figure very close to that found for an ordinary double-ended cylindrical boiler. If built double-ended, Mr Weir gives the weight as 0.568 tons per square foot of grate. The space occupied by the boiler is 4.38 sq. ft. per square foot of grate for the boiler shown in Fig. 210.

EVAPORATIVE TRIALS OF WEIR WATER-TUBE BOILER.

HEATING SURFACE 2,190 SQUARE FEET.

Arrangement of boiler	Single ended.		Double ended.	
Grate surface	48·75	48·75	53	53
Ratio to heating surface	1 to 45	1 to 45	1 to 41·3	1 to 41·3
Draught	Forced.	Natural.	Forced.	Natural.
Date of trial	25th Sept.	26th Sept.	15th Oct.	15th Oct.
Duration of trial	3 hours.	4 hours.	3 hours.	4 hours.
Description of coal	Scotch steam coal.	Scotch steam coal.	Scotch steam coal	Scotch steam coal.
Calorific value of coal *	13·38	13·38	13·2	13·2
Steam pressure lbs. per sq. in.	285	251	275	276
Draught in funnel ins.	3·21	·6	3·5	·625
Draught in combustion-chamber ins.	2·15	·47	2·04	·5
Draught in furnace ins.	·885	·25	1·55	.375
Coal consumed total lbs.	9,072	5,656	10,080	6,160
Coal consumed lbs. per hour	3,024	1,414	3,360	1,540
Coal consumed lbs. per sq. ft. grate surface	62·2	29	63·4	29·1
Feed-water temperature Fahr.	113	130	111	135
Water evaporated total lbs.	70,422	52,950	74,796	52,630
Water evaporated lbs. per hour	23,474	13,237	24,932	13,157
Water evaporated per lb. of coal	7·76	9·36	7·42	8·54
Water evaporated from and at 212° Fahr.	9·05	10·7	8·65	9·76
Water evaporated per sq. ft. heating surface	10·718	6·044	11·38	6·0
Water evaporated per sq. ft. from 212° Fahr.	12·5	6·918	13·27	6·86
Efficiency of boiler	67·65	80·0	65·5	74
Average thickness of fires ins.	12	12	9	9
Clinker withdrawn lbs.	612	449	809	700
Ashes withdrawn lbs.	188	112	156	225
Height of water in glass ins.	8	7·5	6·5	6·5
Funnel temperature Fahr.	...	789	930	780
Total hours steaming to date	1,050	1,074	1,380	1,384
Total hours since tubes were swept	1,050	1,074	119	125

* In pounds of water evaporated per pound of coal "from and at" 212° Fahr. as determined by Thomson's calorimeter.

149. *Yarrow Boiler*.—Amongst the numerous types of recent origin, the Yarrow boiler is possessed of characteristics no less original than those of the Thornycroft, but of

YARROW BOILER OF ALUMINIUM TORPEDO-BOAT C.

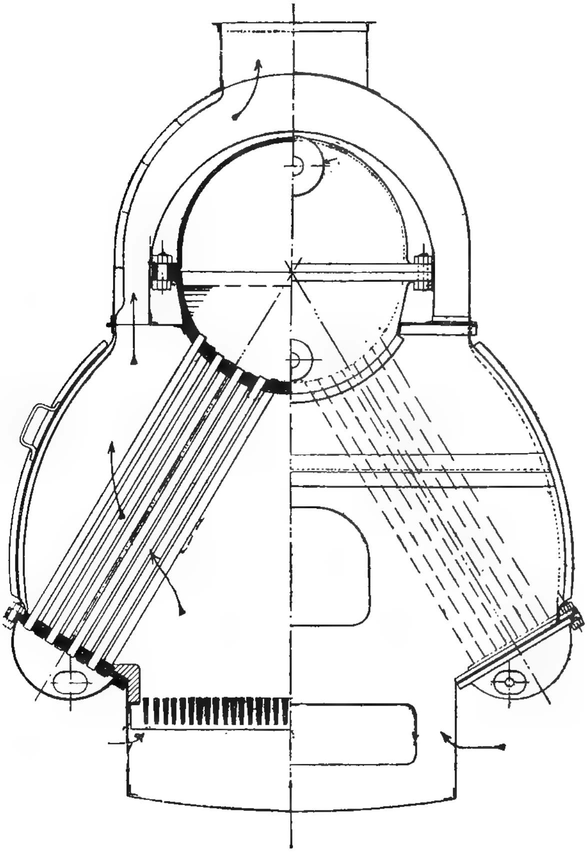


Fig. 211.

quite a different nature. Its chief characteristic is its extreme simplicity and lightness.

Fig. 211 represents the boiler of a small torpedo-boat ordered by the French Navy for the *Foudre*. The tubes are all in a straight line from one chamber to the other;

their lower ends are expanded into a thick flat plate, and their upper ends into a cylindrical barrel, the plates of which are increased in thickness where perforated by the tube holes, so as to allow of the tubes being well expanded. The three chambers are each in two parts with external flanged and bolted joints. Access to the whole of the tube ends is at once obtained on removing the outer segments. The tubes can be cleaned and examined internally

YARROW BOILER.

Scale $\frac{1}{48}$

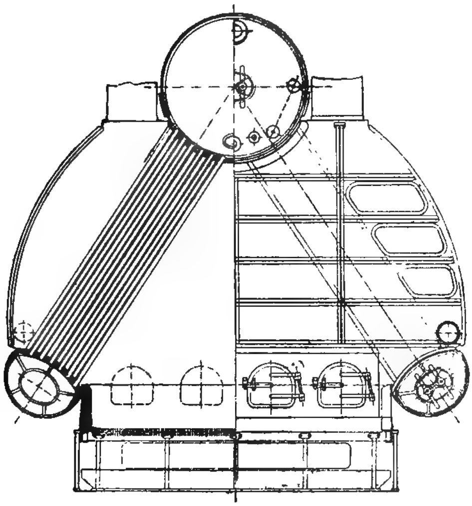


Fig. 212.

with the greatest facility; in an emergency Mr Yarrow effected the replacement of a tube in forty minutes.

In large boilers upper barrels with bolted joints could not be constructed capable of supporting the pressure, and so they are made with the usual riveted joints, and in consequence lose the advantages possessed by the divided barrels; but this is not of much importance as their large size permits of ready access for the examination and replacing of the tubes. The bottom drums are also made of two

different thicknesses of plate riveted together as shown in Fig. 212 illustrating the type of boiler used for large warships. The tubes, owing to their form and arrangement, are extremely easily inspected.

The straight form of the tubes greatly reduces the number of "spares" required and facilitates the replacing of a tube afloat.

Another simplification adopted by Mr Yarrow is the abandonment of large external downtakes. The circulation takes place entirely in the banks of generating tubes, a feature which places the Yarrow boiler somewhat behind the group of those with accelerated circulation, in spite of its evident analogy to the Du Temple and similar types of boiler. Mr Yarrow was led to this arrangement by the results of the curious experiments upon the circulation of water, explained in paragraph 136. He demonstrated that when getting up steam the water in certain tubes would ascend while in others it would descend, and that the circulation thus started would be maintained in the same direction in a permanent manner by reason of the laws of distribution of temperature in a heated circuit, and that therefore downtakes were unnecessary. It should be noted that the observations made by Mr Yarrow, and the conclusions drawn therefrom, are only applicable to straight tubes offering but slight resistance to the movement of their contents.

The suppression of the downcomers is, however, of interest in boilers of the Du Temple type, and the reasoning in the one case would be similar to that in the other, except that the curved tubes would offer slightly more resistance than the straight ones. M. Brillié has considered the subject from a theoretical point of view, and has designed a boiler which is referred to in paragraph 156, but which has not yet received a trial on a practical scale. Mr Yarrow has sectioned off two or three of the external rows of tubes by means

of a small baffle-plate in the bottom drum, and into this space the feed water was fed ; the tubes thus sectioned off formed practically a feed heater, and Mr Yarrow claims an increased efficiency of 5 to 7 per cent. for this arrangement. It has the objection in common with all economisers of exposing one particular section of the boiler to excessive wear.

The course of the gases is across the tubes, and though the shortness of the travel is not conducive to a high thermal efficiency, the large volume over the furnace makes a high total efficiency possible. Results of actual evaporative tests do not, however, appear to have been published, but the results of the following eight hour tests, carried out on one of the nineteen Yarrow boilers for H.M.S. *Warrior* under the supervision of Admirality officers, and kindly supplied to the Editor by Mr Yarrow, are of interest.

Coal per sq. ft. of grate surface per hour. Lbs.	Average draught of air in the base of funnel. Inches.	Water evaporated from and at 212° F. Per lb. of coal.	Water from and at 212° F. per sq. ft. of heating surface. Per hour.	Water from and at 212° F. per sq. ft. of grate surface. Per hour.
24·0	Natural draught. 0·15	11·661	4·72	279
36·0	0·775	10·974	6·65	394
48·0	1·03	11·038	8·93	530

Grate area = 53·35 sq. ft. ; heating surface, 3,163 sq. ft.
H.M.S. *Warrior* has ⅘ths Yarrow ; ⅕th cylindrical boilers.

Mr Yarrow has tried tubes of various materials. At first he used steel ones. Afterwards he adopted brass tubes at a time when they were being almost universally abandoned. He expressed satisfaction with this change at the commencement of 1894, because he had been able to obtain brass tubes of a special make free from the fine cracks mentioned in paragraph 142. Since then he has returned to steel, possibly on account of the changes in the elastic qualities of

copper alloys at high temperatures, or perhaps simply owing to the difference in cost.

The great defect of the Yarrow boiler is the want of flexibility in the tubes, which necessarily tends to start the joints in case of unequal expansion. Mr Yarrow states, however, that the joints, when properly expanded into plates of increased thickness, never show the slightest leakage.

One of the eight boilers of the *Hornet* was submitted to the following severe tests before being placed on board. Pressure was got up in twenty-two minutes by forcing the draught to a pressure of $3\frac{1}{2}$ ins. of water; the boiler was then worked for thirty-eight minutes, when the fires were suddenly drawn, the fire and ashpit doors being at the same time thrown open to the cold air. No trace of injury was observable. This test was severe, but the cooling effects were the same on all the tubes simultaneously. A more convincing fact is the extended adoption of the Yarrow boiler on the English torpedo-boat destroyers, and, as one of the results of the recommendations of the Committee on Naval Boilers (*see* Appendix), on a number of large warships. Besides the *Hornet*, this boiler was adopted for the *Salmon* and the *Snapper*, by Earle's Shipbuilding Company, Hull; the *Hardy* and *Haughty*, by Messrs Doxford, Sunderland; the *Opossum*, *Ranger*, and *Sunfish*, by Messrs Hawthorn, Leslie, & Company, Newcastle-on-Tyne; and the *Spitfire* and *Swordfish*, built by Messrs Armstrong, Mitchell, & Company, at Elswick, and a number of other small vessels.

The *Hampshire*, *Antrim*, *Natal*, *Warrior*, *Achilles*, and *Cochrane* are to be fitted with one-fifth cylindrical boilers, and four-fifths Yarrow boilers of the large tube type. The third class cruisers *Amethyst* and the *Medea*, fitted with Yarrow boilers, have been some time in service, and the *Shannon* and the *Defence*, first-class cruisers of 27,000 H.P., are to receive Yarrow boilers exclusively.

One of the earliest experiences gained was with the *Hornet*, where the Yarrow boilers were in competition with the locomotive boilers of the *Havock*. The principal dimensions of the *Hornet's* boilers, which might be compared with those of the *Speedy* previously given, were as follows :—

Number of boilers	8
Total grate area	164·8 sq. ft.
Total heating surface . . .	8,216 ,,
Ratio of grate to heating surface . . .	49·8 ,,
Total weight (water included)	43·1 tons.
,, ,, ,, ,, per sq. ft. of grate area	0·262 ton.

In completing the comparison with the Thornycroft boilers it should be noted that if the heating surface is relatively less on the *Hornet* than on the *Speedy*, it is, on the contrary, greater than on the *Daring*; on the other hand, the advantage of lightness is certainly less when compared with the *Daring* than with the *Speedy*.

The Yarrow boiler has been fitted to a very large number of torpedo-boat destroyers, gun-boats, and other smaller craft; the most interesting installations, however, have been in the Dutch, Austrian, Swedish, and Norwegian Navies, amounting altogether to over 200,000 H.P. The most powerful installations abroad are, one of 13,000 H.P. for an Austrian cruiser; three of 14,000 H.P. for Austrian battleships; 12,500 H.P. for the *Don Carlos* belonging to the Portuguese Navy, and 12,000 H.P. for a Swedish cruiser.

The general adoption of the Yarrow boiler in the Dutch Navy merits notice. The *Friesland*, *Holland*, *Zeeland*, of 10,000 H.P., are fitted with one-fourth cylindrical boilers and three-fourths Yarrow boilers. Owing to exceptional circumstances, the *Holland*, on a slow-speed run to the East Indies, consumed 2,400 tons of coal, about three times the amount expected. The *Utrecht*, *Gelderland*, and *Nord-Brabant* were fitted with Yarrow boilers only, as also the four ironclads, *De Ruyter*, *Hertog Hendrik*, *Tromp*, and

Koningin-Regentes, thus giving the Dutch Navy the advantage of using one type of water-tube boiler throughout the service.

Plate VI. illustrates three Yarrow boilers built for the Russian Training Ship *Okean*, and have the following dimensions per boiler:—

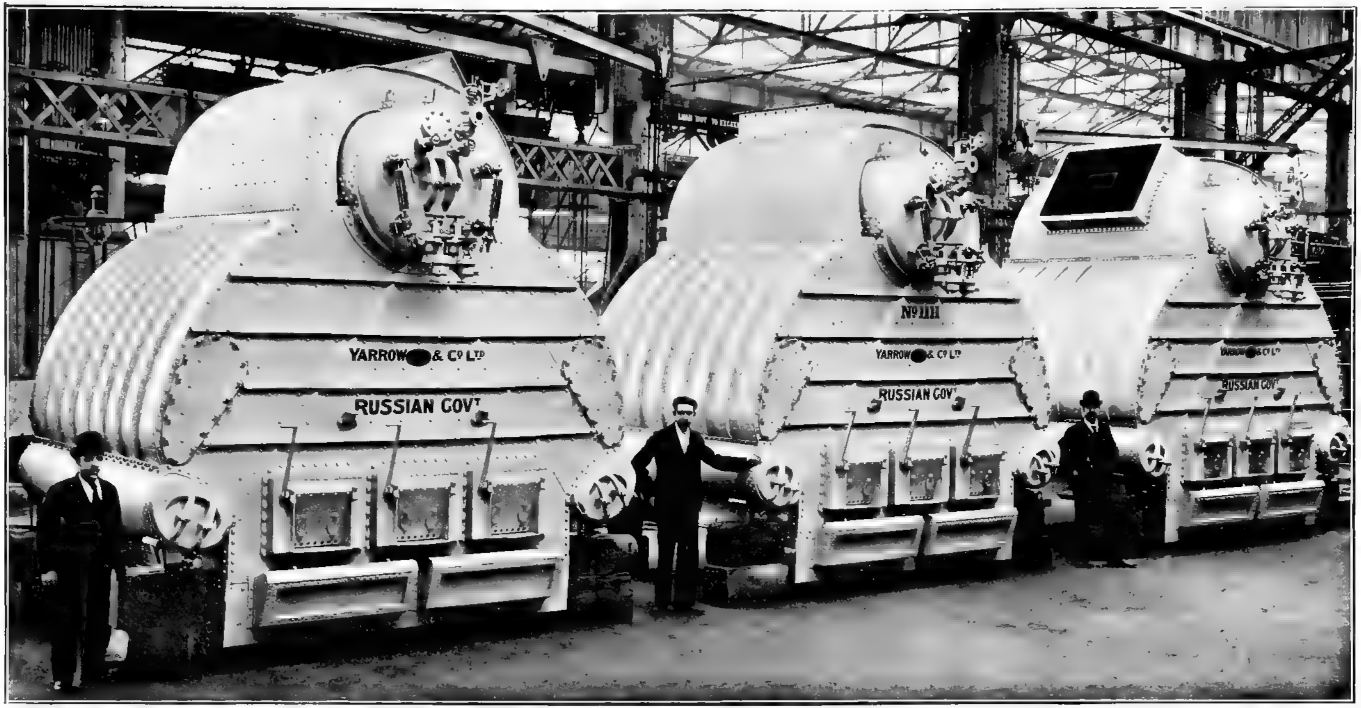
Grate surface	60 sq. ft.
Heating surface	2,983 ,,
Ratio $\frac{H.S.}{G.S.}$	49·7
Weight, dry	17·75 tons
Water	3·75 ,,
Total	21·50
I.H.P.	1,000

The Lagosse boiler, made in one of the French arsenals, is an imitation of the Yarrow boiler, as the Schulz was of the Thornycroft.

One feature worth noticing in the Yarrow boiler is the entire absence of any tube-walls. The main features of the group of boilers to be considered in the next paragraph is their facility for replacing any tube *in situ*. After the Thornycroft and Yarrow boilers, other English types of more recent origin will be briefly noticed.

150. *Blechynden Boiler.—Fleming and Fergusson Boiler.—White Forster Boiler.—Seaton Boiler.*—In the boiler constructed by Mr Blechynden of Barrow-in-Furness, the same facilities for withdrawing and replacing the tubes, as are obtained in the Yarrow boiler with the upper drum in halves, are secured, while permitting the use of a completely riveted upper chamber. All the tubes are slightly curved to arcs of different radii which converge to the same point on the plates of the drum. At this point hand-holes are arranged along the length of the boiler sufficiently close together to allow of the introduction or withdrawal of any

YARROW BOILERS FOR RUSSIAN TRAINING SHIP *OKEAN*.



[*To face p.* 476.

of the tubes, each one of which can thus be removed independently of the others.

As in the Yarrow boiler, to which, on the whole, the Blechynden bears a striking analogy, there are no external downtakes, the water being supposed to descend by the

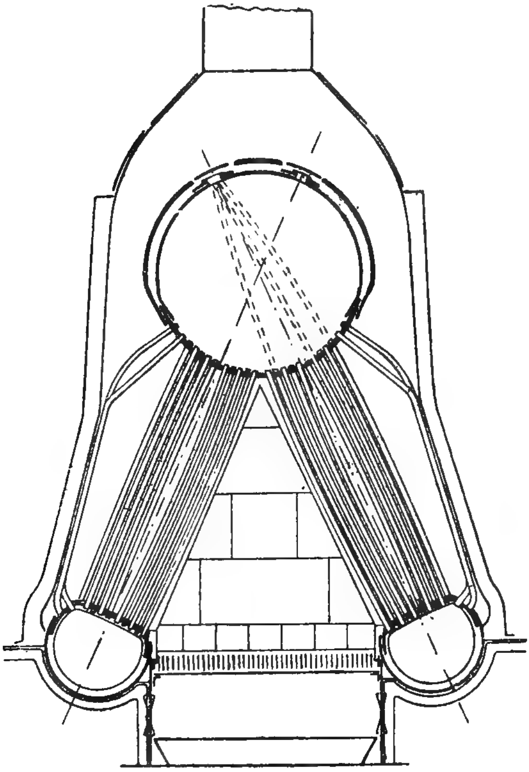


Fig. 213.

two outside rows of tubes, which form a tube-wall for the protection of the casing, and which are further somewhat removed from the banks of tubes.

This type has been adopted for the *Sturgeon*, the *Skate*, and the *Starfish*, built by the Naval Construction and Armaments Company (now Messrs Vickers, Sons, and

Maxim) of Barrow, as well as for the two cruisers *Pactolus* and *Pomone* of the *Pelorus* class, the machinery for which was supplied by Messrs Penn.

The working pressure of the most recent Blechynden boilers is 300 lbs. per square inch for a pressure of 250 lbs. at the engines; this large drop in pressure necessitates the employment of a reducing valve.

The Fleming and Fergusson boiler (Fig. 214) has been specially introduced for use in the merchant service, where questions of maintenance, repairs, and renewal become of vital importance, and where there is not sufficient room around the boilers for withdrawing and replacing the tubes of boilers of the Blechynden type. In order to perform this operation within the limits of the boiler itself, the lengths of the tubes have been reduced and the diameter of the upper drum increased until the tubes can be wholly withdrawn into it.

On account of its large diameter, an upper drum can accommodate more than two banks of tubes. The inventors have designed several types of boilers, some with the grates running longitudinally, others transversely, some of the boilers being single-ended and some double-ended, while one upper drum is sometimes in connection with two, sometimes three, or even four lower drums.

A feature common to all the types is the increased spacing of some of the tubes at their upper ends so as to allow of the crossing of corresponding tubes in both banks, as shown in Fig. 214.

The weight, at least equal to 0.685 ton per square foot of grate area, is not below that of locomotive type boilers, therefore the adoption of the Fleming and Fergusson boiler would be determined by superiority in working and not by any economy in weight.

Mr Samuel White of East Cowes, in conjunction with Mr Forster, has brought out a boiler in which the withdrawal

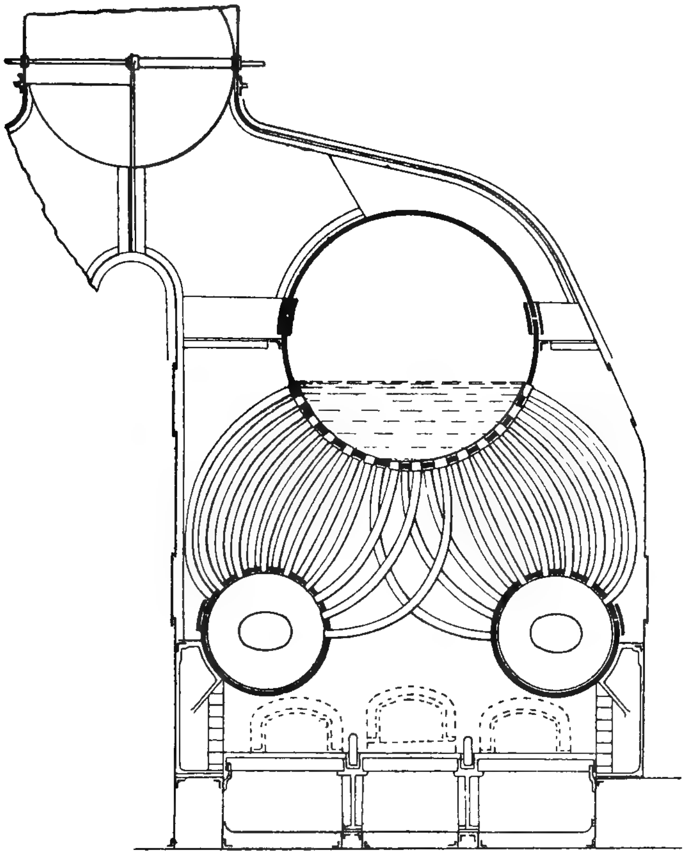


Fig. 214.

—	Boiler with 3 Furnaces (Fig. 214).	Boiler with 6 Furnaces (double-ended).	Boiler with 4 Transverse Furnaces.
Grate area . . . . sq. ft.	50	138	165
Heating surface . . . . „	1,450·5	4,801	5,000
Ratio of heating surface to grate . .	28·98	34·79	30·3
Total weight with water, but without funnel . . . . tons	30	75	110
Working pressure . lbs. per sq. in.	220	200	250

and insertion of the tubes can be carried out entirely in the top drum, as shown in Fig. 215A. In this respect the White-

WHITE-FORSTER BOILER

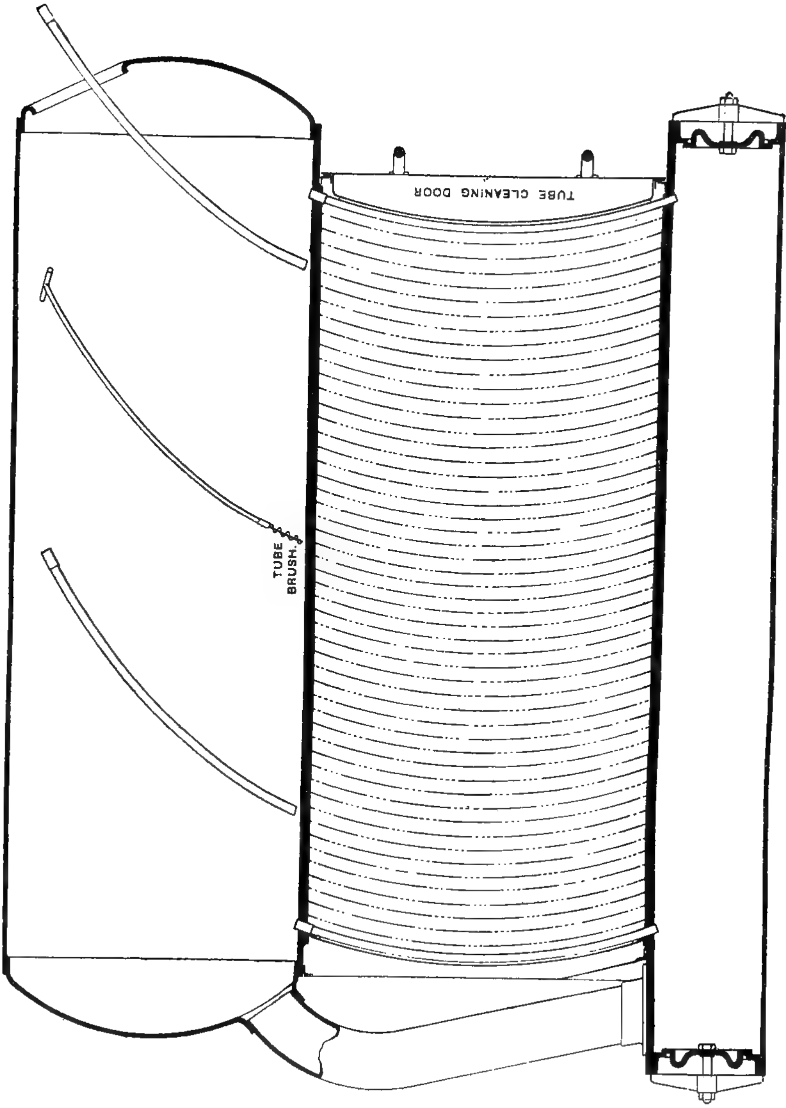


Fig. 215.

Forster boiler resembles the Fleming and Fergusson boiler, as also in the facilities it offers for the cleaning of the tubes

WHITE-FORSTER BOILER

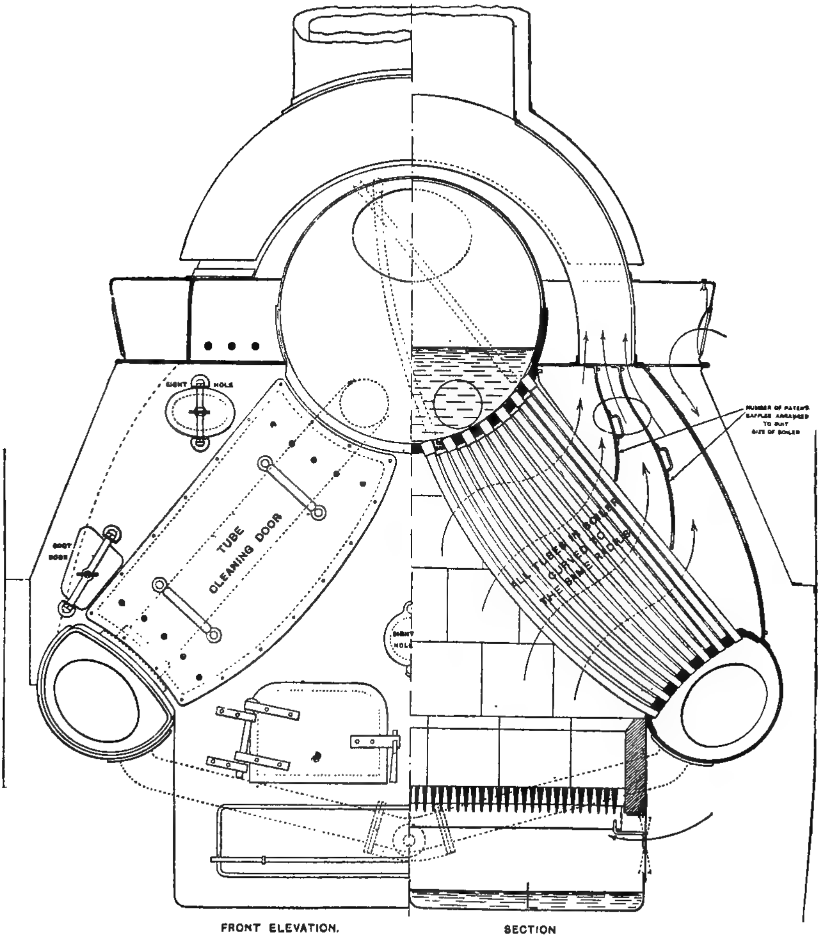


Fig. 215A.

internally by means of a brush which can be worked from the inside of the top drum. Large down-comers are fitted at the back of the boiler.

Fig. 216 illustrates an early type of boiler designed by Mr White which was fitted to some torpedo-boats by the British Admiralty, but has since been abandoned on account of the complicated form of the tubes.

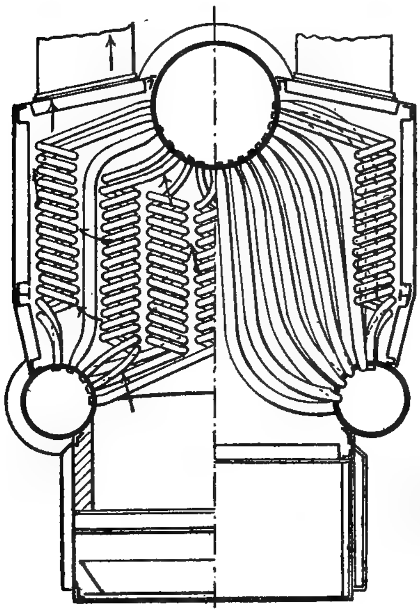


Fig. 216.

The length of the tubes being the principal obstacle to their renewal, Mr A. E. Seaton, of Hull, has designed a boiler in which they are divided into two portions by an intermediate reservoir, into which they can be withdrawn. The Seaton boiler (Fig. 217) has the form of an X. There are two upper and two lower barrels at the extremities of the branches, the intermediate one being at their inter-section.

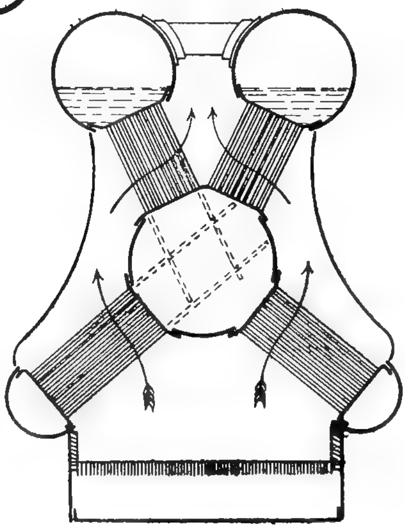


Fig. 217.

The hot gases pass successively across two banks of tubes, playing around the intermediate reservoir on their way, and escape into the funnel by the space between the two upper barrels.

The usual external downtakes connect the two upper

drums directly with the lower ones. On each side is a tube-wall for the protection of the casing. The tubes of this wall are directly connected with the lower and upper barrels; these tubes, which are, however, less exposed to

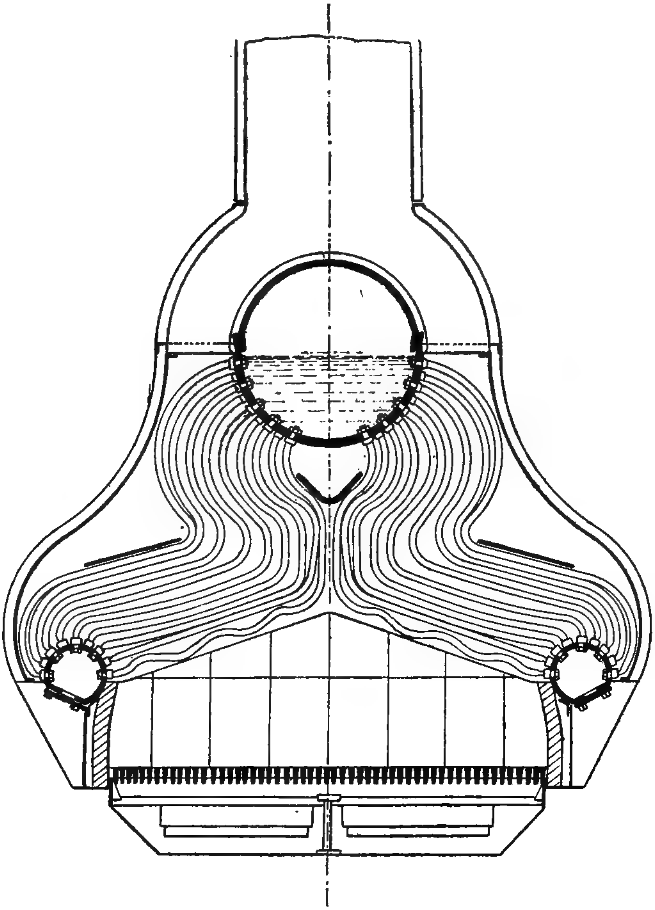


Fig. 218.

heat than the others, do not present the same facilities for removal as those in the principal groups. The two upper barrels are joined together by transverse tubes.

The Seaton boiler appears to fulfil, in a very complete

manner, all the practical requirements of a good marine boiler, as regards maintenance and repairs. The presence of the intermediate reservoir full of water must, however, result in a substantial increase of weight.

151. *Reed Boiler—Mumford Boiler.*—The Reed Boiler (Fig. 218) amongst all the English types is the one which most nearly resembles the Du Temple, having a transversal movement of the hot gases, and tubes discharging below the water-level in the upper drum; the tubes are bent in

MUMFORD BOILER.

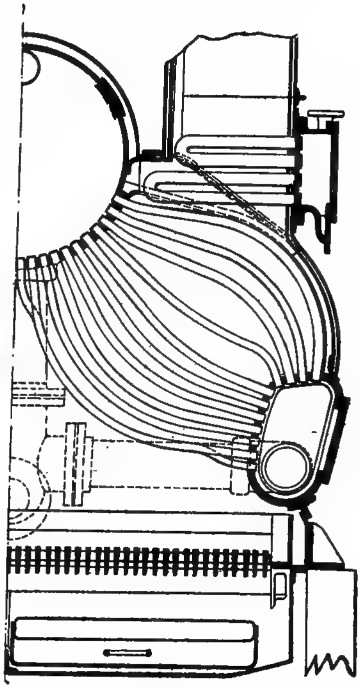


Fig. 220.

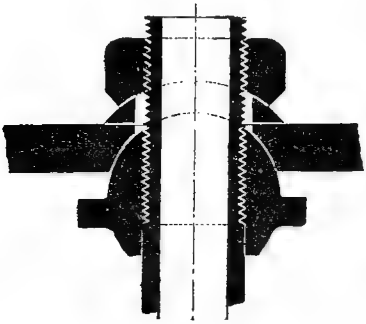


Fig. 219.

a manner recalling the zigzags of the Sochet boiler. The inside row of tubes is bent into a wavy form, which is, however, somewhat unfavourable to the free escape of steam, and has been abandoned in later boilers of this type.

Another analogy to the Du Temple boiler consists in the use of screwed tube connections (Fig. 219), only the joint, instead of being made upon a conical face and a plane face, is made upon two spherical faces, which allows of a certain angular "play" of the tubes.

Reed boilers have been adopted for several English torpedo-boat destroyers—the *Janus*, the *Lightning*, the *Porcupine*, the *Star* and several others. In a coal-consumption trial on land, under natural draught, they have evaporated 12 lbs. of water per lb. of coal from and at 212°.

The Mumford boiler illustrated in Fig. 220 slightly

AGDA BOILER.

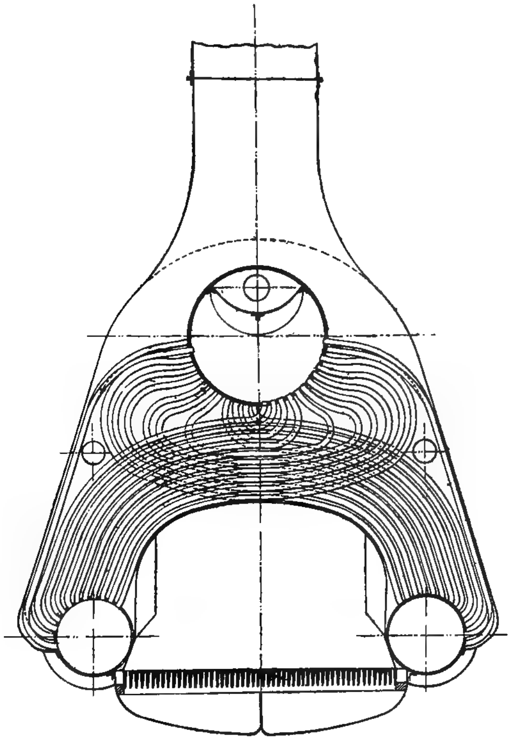


Fig. 221.

recalls the Guyot, and particularly the earlier type of Du Temple boilers, notably in the bottom drums and their side-doors. The U tubes in the up-take act as superheaters.

152. *Swedish Type Boiler.—Ansaldo Boiler.*—An arrangement of tubes which has already been referred to in

Fig. 206 consists of crossing the tubes so that the tubes from the right-hand bottom collector enter the top drum on the left-hand side, and those from left-hand bottom collector enter the top drum on the right-hand side.

About 1895 some boilers of this type were built by the firm of Du Temple, but the ordinary type of Du Temple boiler appears to have been preferred. Fig. 221 illustrates this type of boiler as fitted on the Swedish gunboat *Agda*. The furnace crown is a good deal lower than in the older type, but the arrangement permits of a large amount of heating surface being provided.

ANSALDO BOILER.

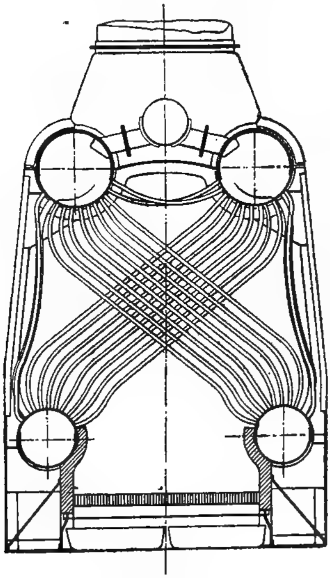


Fig. 222.

A somewhat similar arrangement was adopted by M. Nabor Soliani, and is shown in Fig. 222, from which it will be seen that there are two lower and two upper collectors and the tubes are not crossed to the same extent as in the previous type mentioned. The steam drum placed between the two upper collectors only extends for half the depth of the boiler, and the side casings are protected by tube-walls, the whole boiler being of a compact rectangular form. Boilers whose generating tubes cross in the centre force the gases to traverse the tubes transversely.

153. *Leblond and Caville Boiler.—New Type of D'Allest Boiler.—Haythorne Boiler.*—Boilers whose tubes are not crossed are very much simpler than those with crossed tubes. One of the earliest types of this class of boiler is the Leblond-Caville (Fig. 223), which was fitted on board the Bazin

roller boat. M. D'Allest brought out a design with accelerated circulation shown in Figs. 224 and 224A.

As will be seen from Fig. 224A, the flat water-space at the back has been retained, but a cylindrical drum

LEBLOND AND CAVILLE BOILER (1896 TYPE).

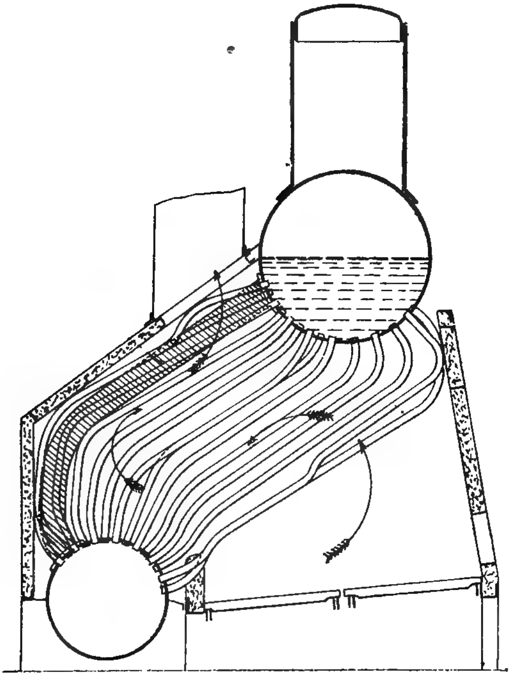


Fig. 223.

substituted for the front water-space; return tubes of large diameter are shown at A. There is a strong likeness between Figs. 224A and 223, and the cross-section (Fig. 224) is practically the same as Fig. 150. The new type of D'Allest boiler has been tried in the French Navy with good results.

The Haythorne boiler, shown in Fig. 225 and 225A, is similar to the D'Allest boiler except that the bottom

horizontal tube-wall takes up more floor space, and the generating tubes deliver the steam into a vertical water space on its way to the steam drum. The form of the generating tubes is very simple, and the downcomers are

D'ALLEST BOILER (1896 TYPE).

Longitudinal section.

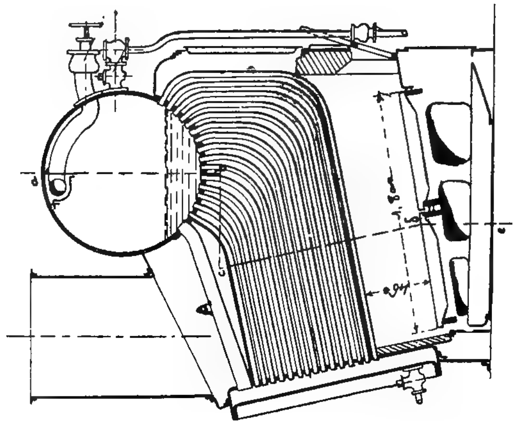


Fig. 224A.

Half section on line a b c d e.

Half elevation.

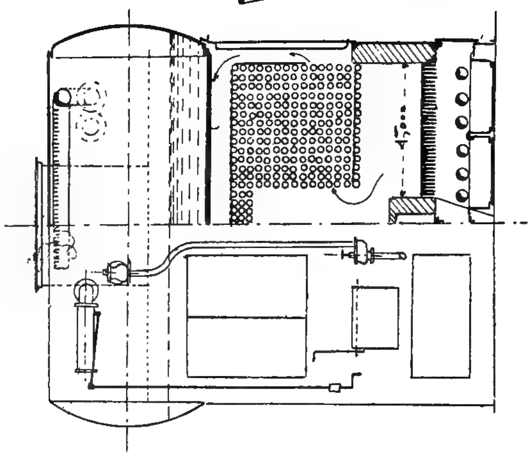


Fig. 224.

at the top inside the casing. The two water spaces are divided into sections similar to the Babcock & Wilcox or Niclausse boilers; they are fixed on the top to the steam collector, and at the bottom to a collector, not

shown in the figure, which serves as feed-collector and mud drum.

HAYTHORN BOILER.

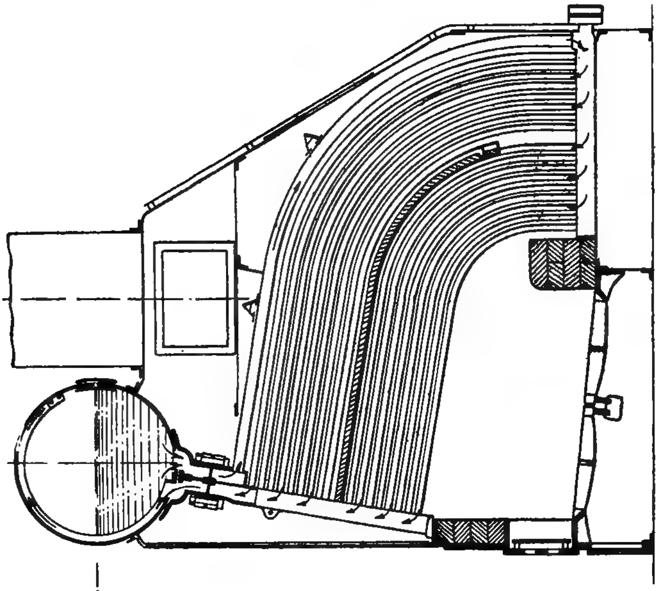


Fig. 225A.

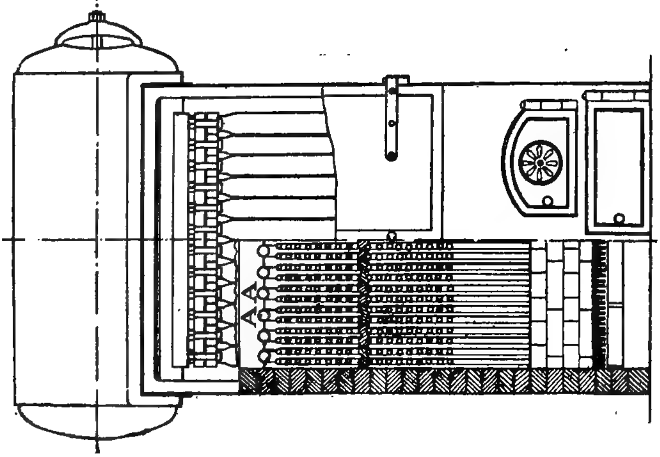


Fig. 225.

The jointing of the tubes is illustrated in Fig. 226; the end of the tube is screwed to a somewhat different

pitch than the ferrule M., and the tightness of the joint is thus secured. The Haythorn boiler has been used on the Caledonian Railway steamers.

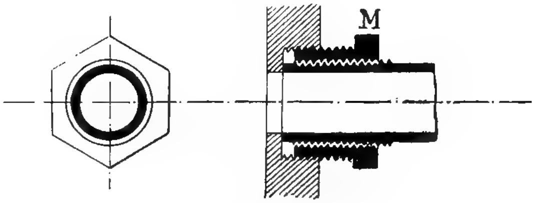


Fig. 226.

154. *Doyère Boiler.—Launch Type of Ward Boiler.*—M. Doyère has worked out a number of different types of boilers consisting of flat cylindrical surfaces with tubes expanded into them. The distinctive feature of the Doyère boiler is that it consists of only two reservoirs composed of conical and cylindrical surfaces and a series of tubes placed symmetrically about an axis *xx*. If the boiler is placed vertically (see Figs. 227, 227A), the grate will be circular and surrounded by the bottom reservoir, the down-comers or return-tubes *aa* being on the outside.

The axis of the boiler may also be inclined at an angle (see Fig. 228A), and the bottom reservoir will then be practically the same as the top one, but of smaller volume; the downcomers *aa* are on the inside, and are protected by a baffle *bb*, which forces the gases to circulate amongst the generating tubes. The furnace in this case will be square and external to the boiler. The types illustrated are only two of the many types suggested by M. Doyère, and in common with the others have the merit of simplicity. The Doyère boilers have been used on destroyers and other small craft which have been constructed during recent years at the Foo-Chow arsenal.

Besides the boiler described in paragraph 124, which was the first boiler fitted in the United States Navy, Mr Ward

DOYÈRE BOILER.

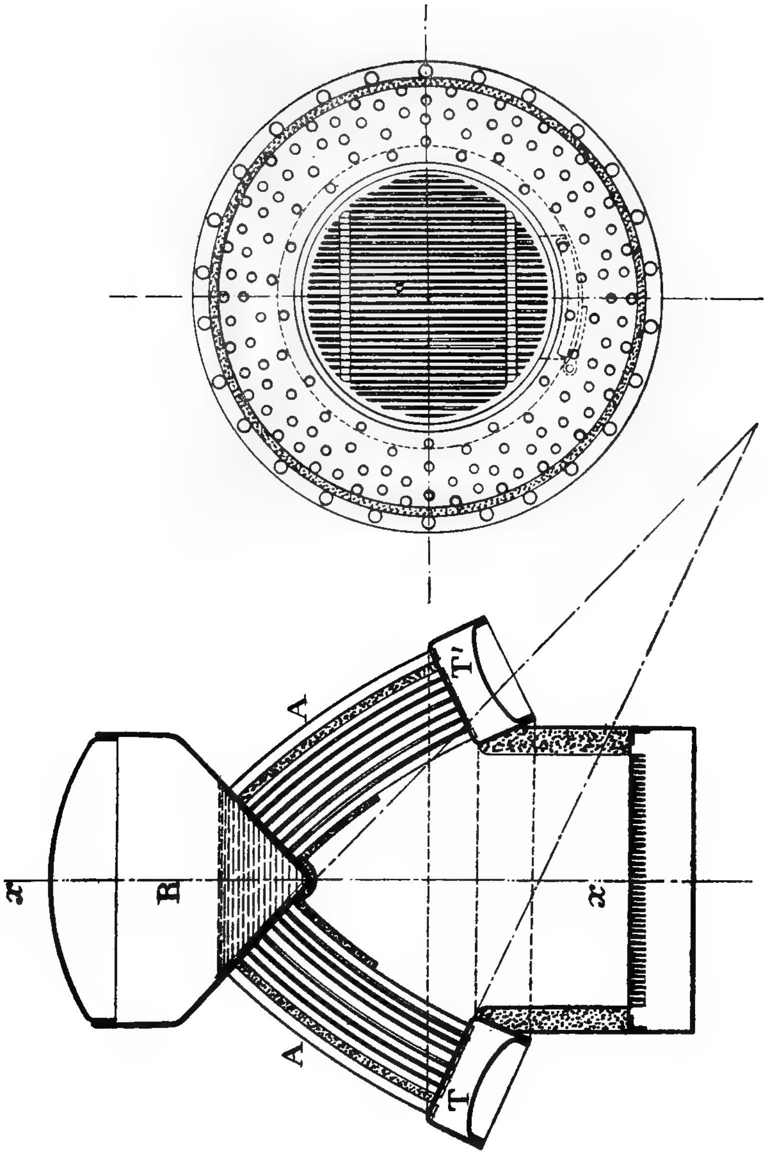


Fig. 227.

Fig. 227A.

DOYÈRE BOILER.

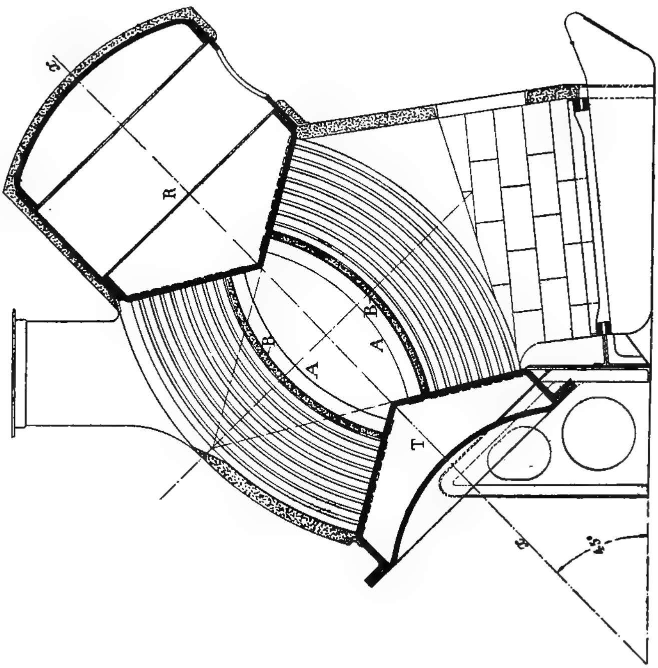


Fig. 228A.

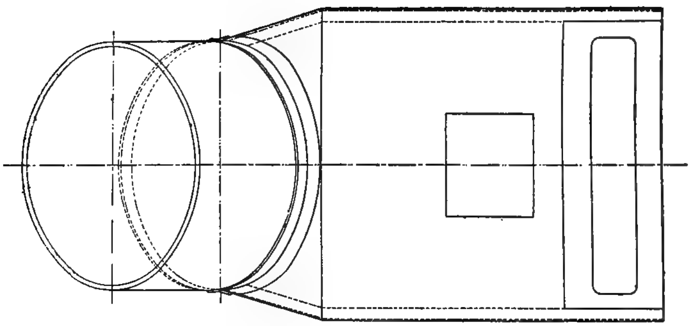


Fig. 228.

designed that shown in Fig. 229; it consists of tubes descending from upper central drums to a very small ring drum running round the bottom of the boiler. The two rows of tubes were supposed to act, one for the ascending and the other for the descending current.

WARD BOILER.

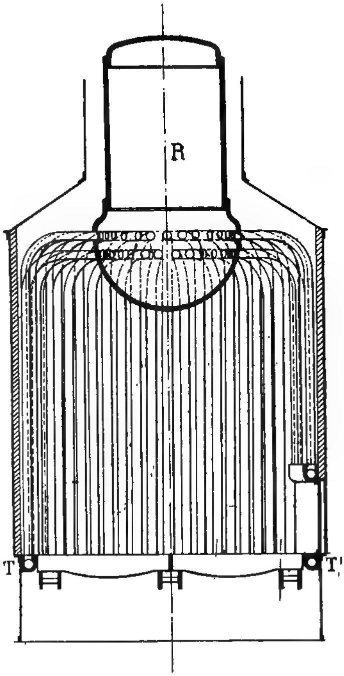


Fig. 229.

155. *Boilers with Field Tubes.—Turgan Boiler.—Borrot Boiler.—Pattison Boiler, etc.*—Field tubes can stand hard firing when the inlet and outlet currents are properly separated so as not to interfere with each other. Mr Turgan maintains that even a steel ball from a bicycle bearing, if placed at the bottom of the tube, will be carried up by the strong entraining action of the upward current. Fig. 230 shows a Turgan boiler which has given very good results on motor vehicles.

TURGAN BOILER.

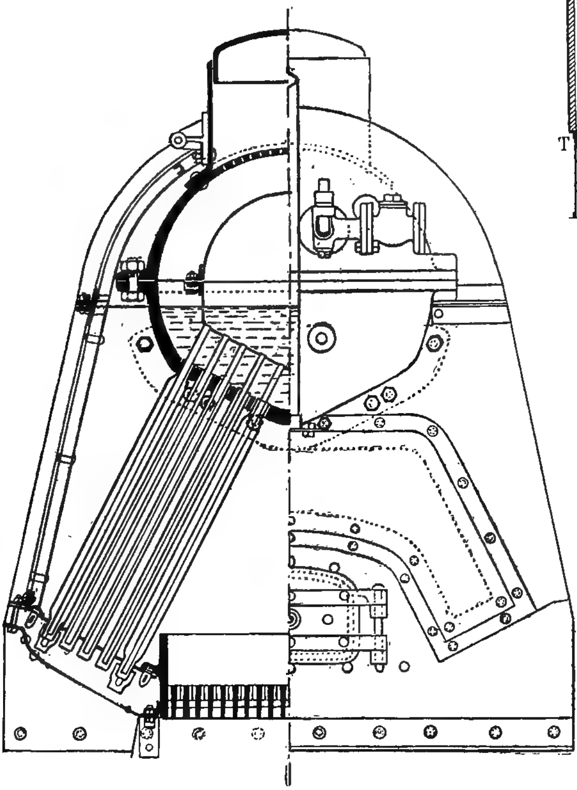


Fig. 230.

BORROT BOILER.

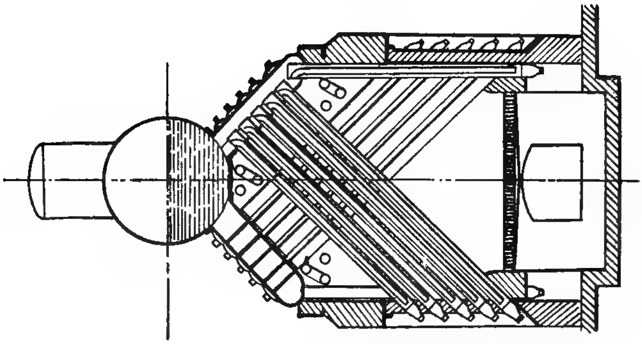


Fig. 231.

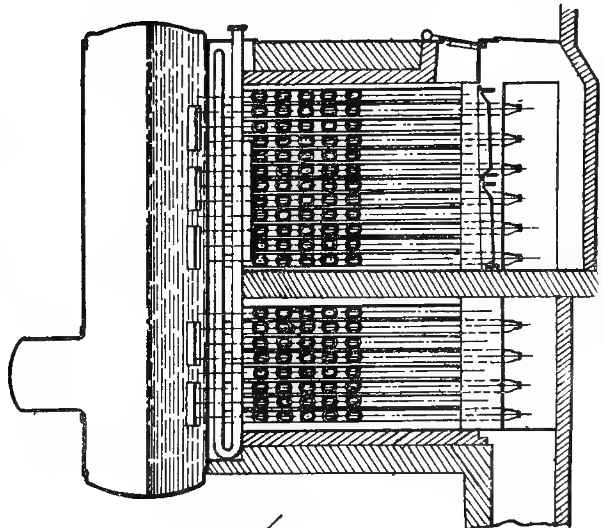


Fig. 231A.

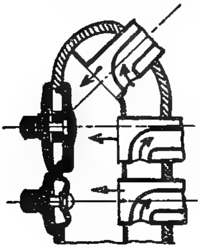


Fig. 232.

Figs. 231 and 231A show the Borrot boiler, which likewise consists of field tubes. The inlet and outlet of the tubes are shown in Fig. 232, from which it will be seen that the water

BRILLIÉ BOILER.

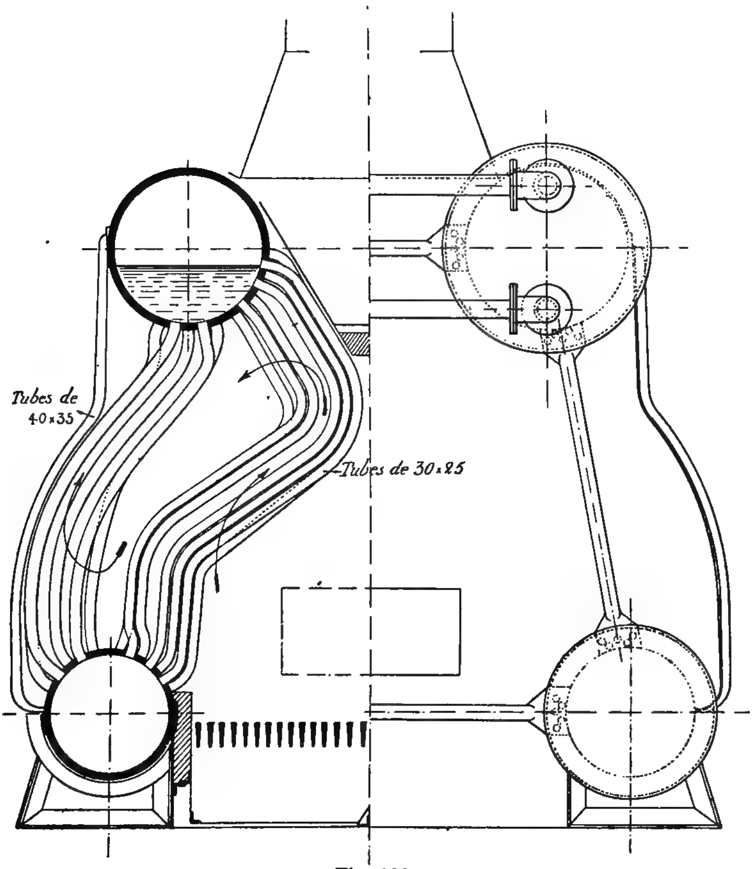


Fig. 233.

enters the central tube by means of a small curved tube, leaving the steam free egress.

The Pattison and the Philips boilers also have Field tubes, but in common with the other two described above, have not so far been used afloat.

156. *Various Types.—Brillié Boiler.—Smith Boiler.—Myabara Boiler.—Stirling Boiler.—Solomiac Boiler.*—A large number of boilers have been invented having accelerated circulation, and one which has received most careful study is that designed by M. Brillié. It has no large outside

SMITH BOILER.

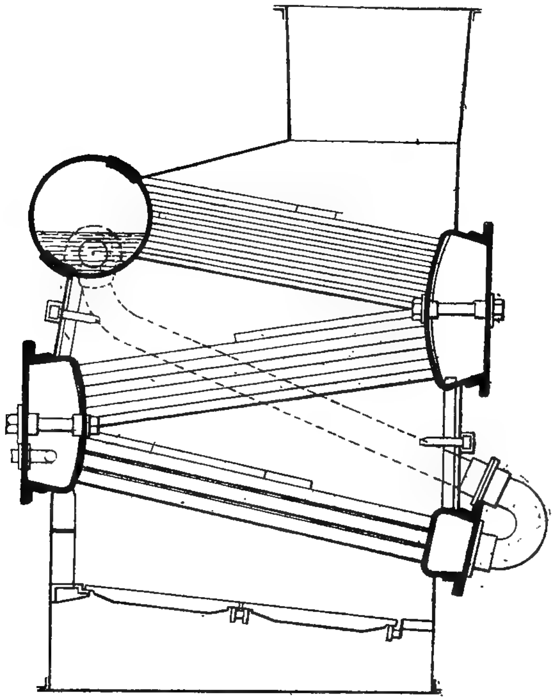


Fig. 234.

down-comers, but there are two sets of generating tubes, the one set for getting rid of the steam, the other set taking the place of down-comers. The former have a diameter of 1.18 ins., the latter 1.57 ins., the thickness being 0.1 in. There are two top reservoirs connected by horizontal pipes, and the space between the two nests of tubes

on either side of the furnace referred to above acts as a secondary combustion-chamber.

Fig. 234 shows the Smith boiler, which resembles the first Sochet boiler, and has tubes of different diameters inclined at various angles over the grate.

MYABARA BOILER.

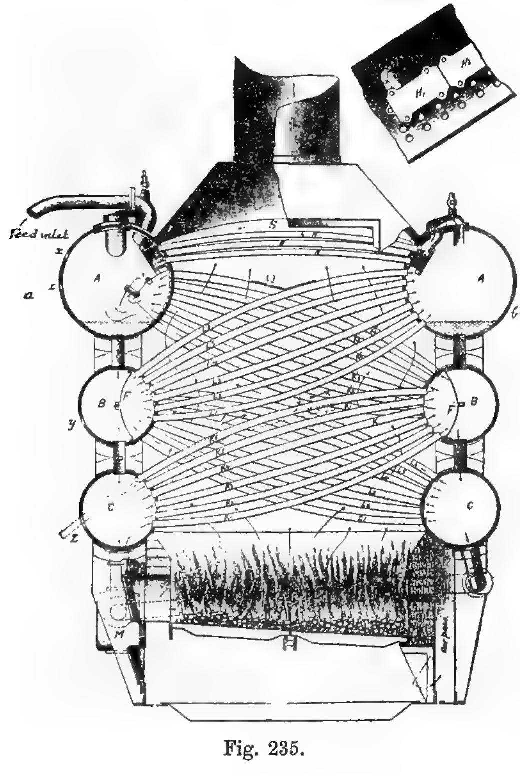


Fig. 235.

Fig. 235 shows a boiler invented by Mr Myabara of the Japanese Navy, which has several drums connected by cross tubes, the upper tubes acting as superheaters.

Another boiler which has several banks of cross tubes is the Stirling boiler, but the tubes approach the vertical more nearly than those of the *Myabara* boiler. This boiler,

like the Babcock & Wilcox, and Ward boilers, is of American origin. It is essentially a large tube boiler, but the form of the generating tubes resembles strongly that of many of the small tube types.

The boiler consists generally of two or more transverse top drums connected to each other by short horizontal tubes. The top drums are again in turn connected to the transverse bottom drum by long generating tubes inclined at about 15° to the vertical, and slightly curved at their ends so as to make them enter the drums radially. The general arrangement of the boiler will be clearly understood by reference to Fig. 236, which gives an illustration of the Stirling boiler as fitted to Messrs. Thos. Wilson & Sons' vessel *Hero* in the beginning of 1903, with, it is understood, most satisfactory results.

The feed-water is introduced into the back top drum, and therefore the back vertical bank of tubes acts more as a feed-heater than anything else, and any sediment or scale is deposited in these tubes, or in the back half of the bottom drum which has a perforated baffle running down the centre, and not in the more highly heated tubes of the front bank. The water gets hotter as it works towards the front bank where the lion's share of the evaporation is done. It has also been purified of its impurities and air, and is in the best condition for the production of steam. The steam generated, on reaching the front top drum, passes backwards through the horizontal tubes connecting the top drums, where it has an opportunity of dropping any water that it may be carrying in suspension, and it finally leaves the boiler by the main stop valve situated on the top of the back drum.

The circulation of the gases, as will be understood by reference to Fig. 236, is across and up and down the banks of tubes. The large combustion-chamber over the grate tends to secure a more perfect combustion than in

HERO OR HIGH SECTION STANDARD BOILER.

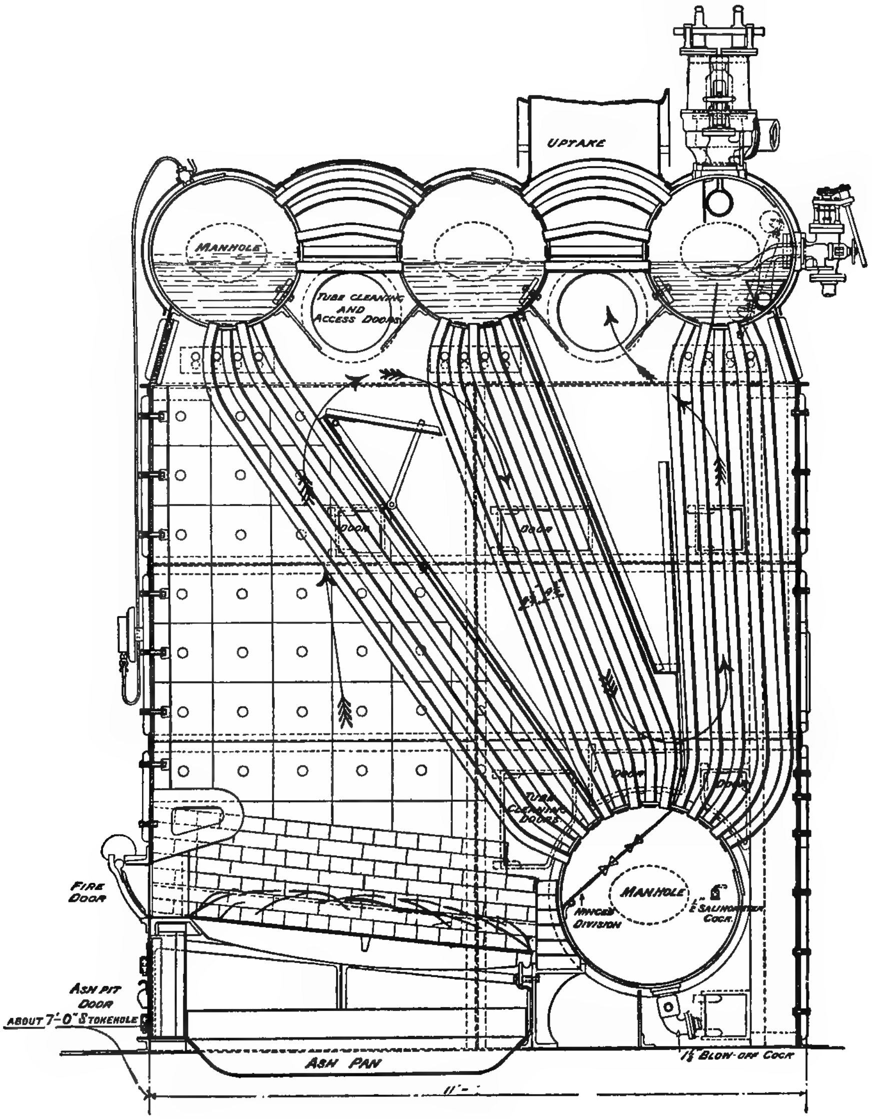


Fig. 236.

those boilers whose tubes are situated close over the grate.

Evaporative tests, carried out by Professor Ewing, when at Cambridge, on a land boiler with natural and with forced draught, gave a high efficiency, with good evaporation, dry steam, and low funnel temperature.

The tubes are merely expanded into the drums, there are no screwed joints, headers, handholes, stays, etc. All the details of construction come under the category of ordinary boilermakers' work. The tubes are easily removed, as one tube is omitted in the centre of each bank through which the tubes can be passed out and in without removing any other tubes.

Not content with the speed of circulation due to difference of head, some inventors, amongst whom is M. Solomiac, propose using mechanical means to effect a forced circulation; but if this class of boiler is to get beyond the experimental stage, it will have to satisfy the stringent conditions as to simplicity required on board ship.

There are a number of other types which might possibly be referred to, but some of these will be found in the Editor's book on "Water-tube Boilers," and need not therefore be referred to at length here.

CHAPTER XIV.

ADVANTAGES AND DISADVANTAGES OF TUBULOUS BOILERS.—COMPARISON OF THE DIFFERENT TYPES.

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§ 1. GENERAL ADVANTAGES OF TUBULOUS BOILERS.

157. *General Advantages and Special Adaptability to Naval Purposes.*—Some of the advantages of tubulous boilers are equally apparent whether for land or marine purposes, and should justify their being more generally adopted on shore than is at present the case. Other advantages are more particularly appreciated afloat, and account for their extended adoption on board ship.

In this chapter the general advantages of tubulous boilers will be first considered, and afterwards their special adaptability to marine purposes, with which this treatise is chiefly concerned.

158. *Ability to stand High Pressures.*—Tubulous boilers are particularly adapted to support very high pressures, because the majority of them, particularly all those having limited or accelerated circulation, are composed almost exclusively of cylindrical elements of small diameter, the pressure in all cases being internal.

In the ordinary cylindrical tubular boilers a maximum pressure is soon reached, which, for the shells, is strictly

limited by the thickness of shell-plates obtainable, and for the furnaces, by difficulties in construction, not yet overcome, and perhaps even insurmountable. With tubulous boilers, on the contrary, no limit of pressure is imposed, except by considerations affecting the working of the engines, and this is solely one of temperature, which may disappear as methods of lubrication are improved.

Tubulous boilers are now commonly constructed for a working pressure of 315 lbs. per square inch, a reducing valve supplying steam to the engines at a pressure of 260 lbs. per square inch. Mr Mosher in America has already used 440 lbs. per square inch at the boiler and 400 lbs. per square inch at the engine, and finality has evidently not yet been reached in this direction.

159. *Comparative Immunity from Accidents.*—The comparative immunity from accidents depends partly upon the ability to support very much higher pressures than the working pressure of the boiler, and partly on the small volume of water and steam contained. Except in their immediate neighbourhood, tubulous boilers are a far less source of danger to surrounding buildings than cylindrical or tubular boilers, as the effect of an explosion is felt over a very much more limited area.

It is no longer possible to speak of immunity for the stokehold staff on board ship since the catastrophes on the *Sarrazin* and *Jauréguiberry*, which were caused by tubulous boilers. Some types, however, have undoubted advantages in this direction. The Belleville boilers, for instance, which have given rise to trifling accidents and caused a good number of scaldings, have not to the author's knowledge been the cause of any accidents attended by fatal results. On torpedo-boats the Du Temple and Thornycroft boilers, for instance, have had the inner rows of tubes next the furnace severely burnt, but these accidents cannot be compared in seriousness

to those caused by a similar shortness of water in boilers of the locomotive type.

The confidence naturally inspired by this type of boiler must not, however, lead to a neglect of the necessary precautions. Thus in boilers of the Du Temple type, where the bursting of a tube may only make itself manifest to those in the stokehold through a fall both in the water-level and in the pressure, an opening of the hatch may, as noted in paragraph 142, lead to a serious accident, as in the case of Torpedo-boat No. 208. Here a fatal coincidence occurred due to the opening of the hatch and fire-door at the same moment. The opening of the hatch alone, however, might have been sufficient to have caused a back-rush of the flames through the ashpan doors.

Given a judicious selection of type, and the necessary care in working, the adoption of tubulous boilers should be attended by a marked diminution in the occurrence of really serious accidents.

Amongst the properties of tubulous boilers tending to prevent accidents may be mentioned the increased durability of the various component parts when subjected to rapid changes of temperature. This point is again referred to in paragraph 167.

§ 2. SPECIAL ADVANTAGES FOR MARINE PURPOSES.

160. *Lightness of Tubulous Boilers. — Consideration of Weight.*—The principal advantage of tubulous boilers for marine purposes over tubular boilers, and the motive dominating their adoption, and justifying the boldness displayed in their introduction, is their great lightness.

The detailed Tables of weights given in paragraphs 102 and 173 permit of minute comparisons being made between

the weights of the various types of boilers, and also between the weights of the several component parts on which the differences principally rest.

In arriving at a comparison between the various types, the official figures will not alone be relied on, but the mean results obtained from statistics of a large number of engines and boilers as supplied by their makers will also be made use of.

The weights found in these statistics differ a little from those taken from the Official Returns and embodied in the Tables in paragraphs 102 and 173, as the latter were taken after the boats had been delivered to the arsenals.

The quantity of water contained accounts alone for more than one-third of the saving in weight realised, and varies greatly with the different types of boiler.

The Admiralty type of cylindrical boiler contains 10.66 cub. ft. of water per square foot of grate, and the return-tube, or Scotch boiler, 7.38 cub. ft., giving a mean of 9.02 cub. ft. for cylindrical boilers.

In locomotive boilers the mean is as low as 4.92 cub. ft., varying between 4.26 and 5.58. Turning to tubulous boilers, the Belleville has only 0.885 cub. ft., the Niclausse 2.07, and the D'Allest type 2.69 cub. ft.

Boilers with accelerated circulation had at first a weight of water equal to that of the Belleville boiler, but it has gradually risen until it has reached that of the D'Allest boiler. The reduction realised in weight of water, however, is more than 0.183 ton per square foot of grate.

The following figures, compiled in 1896, give the total weight per square foot of grate :—

Cylindrical boilers, Admiralty type	1·124	ton.
Single-ended cylindrical marine boilers	0·85	,,
Double-ended marine boilers	0·814	,,
Locomotive boilers for ships	0·96	,,
,, ,, torpedo-boats	0·549	,,
Belleville boiler	0·53	,,
D'Allest boiler	0·539	,,

Niclausse boiler	0·466 ton.
Du Temple boiler (old type)	0·329 ,,
,, ,, (present)	0·411 ,,
Normand boiler (present)	0·421 ,,
Thornycroft boiler (old type)	0·356 ,,
,, ,, of H.M.S. *Speedy*	0·453 ,,
Normand-Sigaudy	0·486 ,,

The weight per square foot of fire-grate of modern tubulous boilers considered suitable for use on large ships is very nearly half that of the ordinary return-tube cylindrical boilers. The weight of the lightest class of tubulous boilers is about one-third those of Admiralty cylindrical type, that is to say, merely equal to the weight of water contained in these latter.

Boilers with accelerated circulation, suitable for use on large ships, will apparently be about 10 per cent. heavier than Belleville and Niclausse boilers, but will be about 10 per cent. lighter per I.H.P. per square foot of grate surface.

In the preceding Table only the weights of boilers for warships have been given. In the merchant service, according to the figures given for two transatlantic liners in the Table, paragraph 102, the weights amount to 1.27 tons per square foot of grate.

The adoption of Belleville boilers by the Messageries Maritimes has, therefore, reduced the weight of the boilers 40 per cent., and that without the use of forced draught.

The weight per square foot of grate would represent the relative weights of different boilers if the evaporative power per square foot of grate were the same for all. This is very far from being the case, especially in the navy, where forced draught is almost universally used. The relative weights of boilers can thus only be determined after very careful examination, which in the nature of the case must be incomplete, as it is impossible to determine with any exactness the maximum evaporative power of a boiler.

The real coefficient of lightness, the weight per horse-

power, is equal to the weight per square foot of grate surface divided by the maximum horse-power per square foot of grate surface, always supposing the weight of steam per horse-power required by the engines to be a constant quantity.

The relative weights can only be determined by the ability of the various types to stand forcing.

161. *Ability to Stand Forced Draught.*—From this point of view, tubulous boilers may be divided into two very distinct groups.

Firstly, types with limited and free circulation, especially constructed for regular working at a moderate air pressure. In these the steam does not get away with great freedom; the passage of the flame among the tubes is short and the volume of the combustion-chamber is, as a rule, small. The maximum horse-power developed afloat up to the present time has been, in the Belleville and the Niclausse boilers, from 12 to 13 horse-power per square foot of grate, and 16 horse-power in the D'Allest boilers of the *Cassini*. These boilers have the advantage of a large combustion-chamber, qualified, however, by the inability of the generating tubes to stand hard forcing. On board torpedo-boats, the Oriolle boilers have been pushed to 22.9 horse-power per square foot of grate, but the production of smoke at that power became excessive. On the *Téméraire*, fitted with Niclausse boilers, and with uneconomical engines consuming 4.27 lbs. per I.H.P. per hour, 15.5 horse-power per square foot of grate was developed, but accidents with bent and burst tubes occurred. All these boilers appear to be made, in actual working conditions, for an output of about 14 horse-power per square foot of grate.

Secondly, boilers with accelerated circulation, constructed specially for torpedo-boats, and afterwards applied to other vessels, and capable of working at high rates of forcing. In these the steam can get away with great

freedom; the flame passages are generally long, the furnace is usually high, and they are sometimes fitted with a small lateral combustion-chamber for the return of the hot gases.

The latest types of the Du Temple and the Normand boilers have given, without inconvenience, up to 37 and 41 horse-power per square foot of grate.

In comparing cylindrical boilers, giving about 18 horse-power per square foot of grate surface, and locomotive, giving 32 horse-power, with the tubulous type, we find that tubulous boilers with limited and free circulation are inferior as regards combustion to tubular boilers, but that tubulous boilers with accelerated circulation are superior to them.

At the rates of working above referred to, tubulous boilers of both groups have, without exception, the advantage that they distress their principal elements very much less than cylindrical boilers. Their tube joints are more easily kept cool and much less subjected to the action of heat, and there are no furnaces to bulge or collapse.

If the figures of 14 and 37 horse-power per square foot of grate surface, given above, be accepted as correct for tubulous boilers, and compared with the figures contained in paragraphs 102 and 173, we find that the weight per horse-power of the Belleville, D'Allest, and Niclausse boilers is two-thirds that of a cylindrical boiler giving 18 horse-power per square foot of grate surface. For the Du Temple or Normand boilers this same ratio falls to one-fourth. It is apparent that for these latter the practical difficulties of stoking in large ships will hardly permit of an output much greater than 18 horse-power per square foot of grate; the ratio of the weights will remain between one-half and two-fifths; and the fact of working the boiler below its maximum capacity must add to the security.

162. *Rapidity in Getting up Steam.*—Pressure can be got

up in tubulous boilers within one hour, while cylindrical boilers usually require four hours. This is an advantage in the navy; but its importance should not be over-estimated, on account of the long operation of warming up the engines, to which not less than ten or twelve hours is given on merchant steamers in order to prevent any mishaps at starting. Ease of shipment and rapidity in raising steam are among the most valuable qualities of tubulous boilers.

§ 3. VARIOUS CONSIDERATIONS.

163. *Horizontal Space Occupied.*—The horizontal space required by a boiler may be expressed by the ratio of the surface formed by the vertical projection of its horizontal dimensions to the grate area. The division of tubulous boilers into two groups, in respect to forced draught, is also applicable as regards horizontal space occupied.

The Belleville, D'Allest, and Niclausse boilers take up little horizontal space. The coefficient of floor space for the Niclausse boiler, which is the lowest of all, is 1.5; it is 1.7 to 1.8 for the D'Allest boiler, and between 1.6 and 1.7 for the Belleville boiler.

The Du Temple and, above all, the Normand boilers occupy somewhat more space. The coefficient averages 2.5 for the Du Temple and Guyot boilers, and reaches 3 for the Normand boiler, on torpedo-boats to 2.5 on large vessels.

Going back to cylindrical boilers, and leaving on one side those types whose furnaces are at one end and tubes are at the other, which naturally occupy a large amount of space, it is found that the mean coefficient of horizontal space averages 1.75 for double-ended boilers and 2 for single-ended boilers. The tubulous boilers in the first group are, therefore, superior to those of the second group,

but inferior to return-tube cylindrical boilers with the same grate area.

If, for large steamships, the powers per square foot of grate given above for each type be accepted, we find that the tubulous boilers of the first group occupy about the same horizontal space as cylindrical boilers, and those of the second group, a space a good deal larger.

164. *Price of Tubulous Boilers.—Their Durability.*—The classification followed in the preceding section holds good from the point of view of cost, as well as working conditions, but particulars in any way reliable can only be obtained for the boilers in the first group, as these alone, up to the present, have been applied to any extent in large ships. The price per square foot of grate of the Belleville boilers, bought by the French Navy during the last few years, has varied between £27.12 and £35.62; on an average, £31.96. The Niclausse boilers of the *Friant* have also cost £31.96. For the D'Allest boilers the price is a little higher; it has ranged from £27.12 to £38.64; on an average, £33.45. The difference is insignificant, and would bear no influence upon the choice made between these three types.

Comparing the average price of cylindrical boilers with the foregoing, we find it to be £32.7 for single or double-ended return-tube boilers, £48.31 for direct-tube or Admiralty boilers, and £52.76 for boilers of the locomotive type. The comparison on this basis is favourable to tubulous boilers. In reckoning the performance per square foot of grate, these tubulous boilers are 25 per cent. dearer than the return-tube boilers, but they are 10 per cent. cheaper than the Admiralty boilers, which supplanted the return-tube boilers.

An endeavour to classify the different tubulous boilers adopted in the French Navy according to their price reveals wide discrepancies in prices of boilers of the same

type. The price of the Belleville boilers, which was £45 per square foot of grate for the *Tully*, rose to £53.5 for the *Victor Hugo*. The Niclausse boilers for the *Gloire* and the *Condé* rose from £46 to £53.8 for the *Léon Gambetta*. For boilers of the Du Temple type the discrepancies were even bigger, the boilers of the *Dunois* and *Lahire* were £64.8, and the large boilers for the *Montcalm* were £67 per square foot of grate. These prices, which are analogous to the price £65 for the cylindrical boilers of the *Fleurus*, were evidently estimates on the part of the builders, and were somewhat wide of the mark. The amounts allowed at Indret for the boilers of the *Jeanne d'Arc* were £44.7 and for the *Jules Ferry*, £40.6, including establishment charges, but without allowing for workmen's pensions. The actual price for the *Jeanne d'Arc's* boilers came out at £28.2, in spite of an omission which had to be rectified during construction. The most interesting comparison would be between the boilers of the Du Temple type on the one hand, and the Belleville and Niclausse boilers on the other hand. On the assumption that the former furnish 20 to 25 per cent. more power per square foot of grate than the latter, and if the contract price is taken as a basis of comparison without taking into account the life of the boiler, the cost per horse-power comes out very nearly the same for all types.

The figures cited above are for boilers fitted with all their accessories, as given in the Table in paragraph 173, the accessories accounting for 37 per cent. of the total price. The real price, after all, depends very largely on the life of the boilers, and in regard to tubulous boilers experience is not as complete as might be. The Belleville boiler is the only one which has been in use in the French marine for any considerable time. Experience has shown that the annual overhaul of the boilers has a vital importance on their life, but the expenditure varies consider-

ably in different ships, and it is almost impossible to tell at what epoch the repairs have amounted to practically replacing the boilers. For instance, in 1891 the Belleville boilers of the *Milan* were put into a good state of repair, but the vessel had to be put out of commission after two or three months at sea. Similar boilers on the *Voltigeur*, on the other hand, after being constantly renewed during the period of twenty years, lasted out successfully several commissions, and attained the same life as the hull. From this and other similar data it is quite evident that the care exercised in the maintenance has an enormous influence on the life of the boilers. The proper extraction of the air from the feed-water has a very marked effect on the life of both cylindrical and tubulous boilers. The presence of air assists corrosion, and the recent results attained with the *Europa's* Belleville economisers are conclusive evidence on this point.

Cylindrical boilers, under certain conditions of work and maintenance, may have a very long life without necessitating any very extensive repairs. The case of a vessel of the White Star Company has been referred to in paragraph 101, where the boilers worked satisfactorily for twenty-four years; also that of the *Notre-Dame-du-Salut*, whose boilers had seen twenty years of service up to the time the boat was chartered by the French Navy. A tubulous boiler would not, in all probability, have reached this advanced age without often having had different parts replaced by new ones. Therefore, in shipping companies, directors, when they can depend on their men, prefer the old types, upon which they can rely with greater confidence.

Care must be taken not to draw too general conclusions. Cylindrical boilers, since their brass tubes have been replaced by iron tubes, are not proof against accidents even at sea. A commission similar to that of the *Marceau* is as unfavourable to the cylindrical boilers as that of the *Milan* was to the

Belleville boilers. Again, note must be taken of the time the boats are laid up, or, what is sometimes more disastrous, of their being out of use for a short time. On men-of-war the life of the cylindrical boilers used to be about eight or ten years at most, with an occasional refit. At the end of this period they were condemned and broken up, though they still contained many sound parts. At the end of ten years a tubulous boiler may not have experienced a thorough overhaul, but will have undergone a good many repairs. Some parts may have been changed twice or even three times without in any way prejudicing the other portions of the boiler which have remained intact, and there is no reason why the boiler, as a whole, should be condemned. Hence the facility of repairs largely compensates for the rapid deterioration of certain portions of tubulous boilers.

Tubulous boilers have a marked advantage over locomotive boilers under the conditions subsisting in torpedo-boats. These latter had often to be replaced after three years' service; extreme care might result in a life of five years. The life of the boilers of the Du Temple type averages about nine years. Thus, leaving out of account the early and somewhat experimental boilers fitted in the years 1882 to 1888 the life on Torpedo-boat No. 137 was ten years from 1891 to 1901, and eight years on the *Dragon*, from 1892 to 1900; a new set of tubes being fitted in the interval. A life of eight years with retubing after five years may now be safely counted on, and it is hoped still to increase this. The development and use of apparatus for prolonging the life of the boilers in conjunction with the experience gained by the *personnel* should lead to an increased life in the future.

From the above statements, some of which might, at first sight, appear contradictory, may be drawn at least one very evident conclusion. In the selection of any particular type of boiler, the question of price and life can only have a

secondary influence. The technical considerations must entirely outweigh the former.

165. *Ease of Repairs.—Difficulty in Stopping Tubes.*—Tubulous boilers composed of elements in juxtaposition and generally detachable, can be made good in case of mishap by simply removing the defective parts and replacing them by duplicates. This work can always be done on board even when skilled workmen are not available.

Tubes can be replaced in some boilers with extraordinary ease; thus, in the Niclausse boiler, the replacing of a tube requires no more than two minutes, once the boiler is emptied; in the Belleville boiler, a complete element can be removed and replaced by another in two hours. In the Du Temple boilers and others of the same class, the operation is complicated on account of the necessity of removing several tubes before arriving at the one whose removal is necessary; but each tube can be withdrawn without trouble from its position; it only means the slackening of a screw or a few blows with a hammer on a drift; in the D'Allest boiler alone does the removal of tubes present more difficulty than in the case of cylindrical boilers.

Repairs to tubulous boilers, even although they should require a stoppage of a few days, instead of merely drawing the fire for a few hours, as is usually the case, are mere child's play compared with the repairs occasioned by the overheating of the furnaces or the combustion-chambers of cylindrical boilers.

With regard to facility for carrying out repairs to the boilers while in commission, it must be remarked that the plugging of the tubes while at work in case of their leaking is an impossibility inherent in the principle of tubulous boilers. The emptying the boiler until the water is below the tube that requires plugging, which involves at times the complete emptying of the boiler, is an absolute necessity.

As regards plugging the tubes, after the fire is out and the boiler emptied, the various types of tubulous boilers present very different facilities, which depend on their mode of construction. In the Belleville boilers, and in general in all boilers unprovided with collectors, it is impossible to plug the tubes. The damaged pieces always have to be replaced.

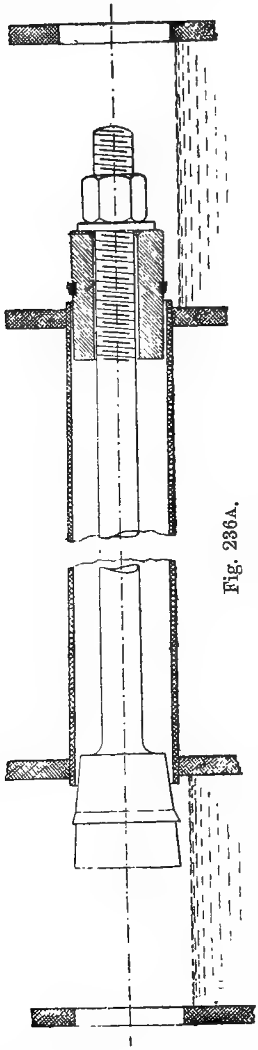

Fig. 236A.

In the D'Allest boilers and in all those with straight tubes, the plugging can be done exactly as in cylindrical boilers, by the use of the ordinary arrangement of double plugs.

Fig. 236A represents a plug specially used for the D'Allest boilers, which is the design of M. Girard, inspecting engineer in the French Navy.

In the Niclausse boilers no question of plugging arises, as the operation is precisely the same as the changing of a tube.

In the early Du Temple boilers the plugging was very easy, owing to the form of screwed joints used, provided that the screw threads inside the collector were in good condition. It is sufficient to remove the nut from the end of the tube and replace it by a blind nut. The blind nuts adopted for this purpose (Fig. 237) are the invention of M. Portay. Owing to the time necessary for the boiler to cool down, the operation takes altogether four hours, counting from the time the fires are drawn until the refilling of the boiler.

If the screw thread is in bad condition and it is necessary to cut the tube so as to insert a plug (Fig. 238), the operation takes at least an hour longer. In the latest boilers with steel joints the necessity of cutting the tubes will be much more frequently met with than was the case with the old pattern brass joints.

In the Normand boilers, and in general in all those wherein the tube joints are made by an expander, the

Tube with Blind Nut.

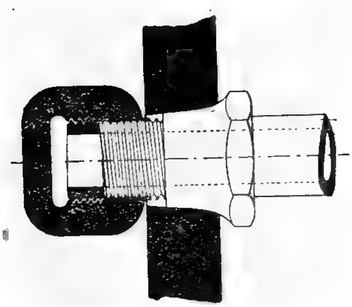

Fig. 237.

Conical Plug used to replace Tube.

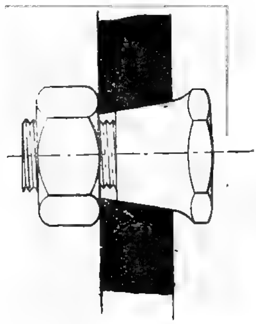

Fig. 238.

class of plug shown in Fig. 238 could evidently be used; but as a rule a simple conical plug (which sometimes has a slight thread cut on it) is inserted into the end of the tube from the inside of the drums. The pressure in the boiler tends to tighten the plug.

The impossibility of plugging a tube while under steam might place a small craft with only one boiler in a very precarious situation during bad weather.

To the inconvenience of having to empty the boiler, must be added the difficulty, often considerable, of locating the fractured tube. There are a number of similar problems of a practical nature for which a solution has yet to be found and which are consequent upon the introduction of

water-tube boilers. Attempted solutions of two of these problems are referred to in the next paragraph.

166. *Ravier Automatic Tube-Stoppers.—Vinsonneau Tube Inspection Apparatus.*—As the pressure in tubulous boilers is on the inside of the tubes, it ought to be possible to devise a means of automatically closing or stopping the tube, should it burst, by means of the pressure existing in the boiler.

An attempt has been made by M. Ravier, a retired engineer officer of the French Navy, and is illustrated in

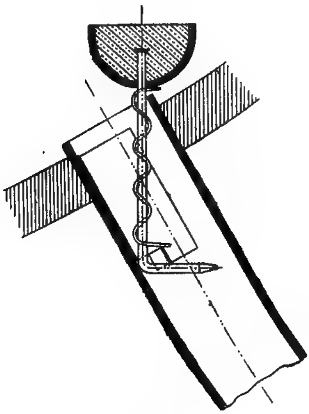

Fig. 239.

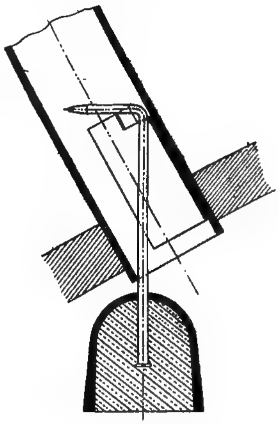

Fig. 239A.

Figs. 239 and 239A, which sufficiently explain themselves without further description. Actual tests on board a torpedo-boat, fitted with a boiler of the Du Temple type, gave very satisfactory results. A tube gave way at the commencement of the trial trip, which, however, was able to be completed and the fires relighted next morning without any repairs having to be carried out on the boiler.

The Ravier tube-stopper successfully carries out the end for which it was designed, but the fitting of anything which would be likely to impede the circulation or close

the tube inadvertently, would probably be sufficient to prevent the extended use of the Ravier tube-stopper or any similar arrangement, at least in the British Navy.

In order to locate leaky tubes, the Vinsonneau apparatus, illustrated in Fig. 240, may be used before emptying the boiler. The apparatus consists of a simple iron tube furnished at one extremity with a little mirror *a* and an electric lamp, and at the other end a second mirror *b* (with adjustable screw), and a telescope.

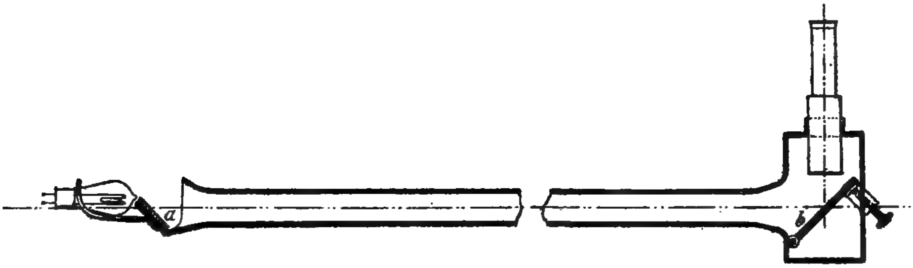

Fig. 240.

The stopping of the tubes and their external examination are no longer so important to-day as they were in the early days of the introduction of water-tube boilers. The improvements in construction and the purification of the feed-water and precautions taken to prevent corrosion when the boilers are laid up have made the occurrence of faulty tubes much more rare.

167. *Ability to stand Sudden Changes of Temperature.*—The majority of tubulous boilers, that is to say, the Niclausse boiler, amongst those with free criculation, and all the boilers with limited and accelerated circulation, are able to stand without injury the most sudden changes of temperature, as evinced by the fact that the fires can be withdrawn in full swing, and all the doors opened without prejudicially affecting the boiler. M. Niclausse thinks nothing of submitting his workshop boiler to this rude test, to the great

edification of his visitors. The similar experience of Mr Yarrow, described in paragraph 149, and the method of removing soot employed by M. Normand's stokers, described in paragraph 48, corroborate the above facts.

It is not fully appreciated, although it ought to be, how sensitive tubular boilers are to sudden changes of temperature even very much less abrupt than those which have just been mentioned. The sudden reduction in the rate of working while under full steam, due to opening the fire- and smoke-box doors, is quite sufficient to stress all the plates of the furnaces, combustion-chambers, and smoke-boxes beyond the limit of elasticity. This gives rise to leaky tube-plates and distortion of the crown plates; and may lead ultimately to leakage along the seams, paving the way for a possible future fracture at the joints. The firing in tubular boilers ought always to be very regular and uniform.

Were it not for the possibility of priming, in case of sudden variations of engine-speed, tubulous boilers would enable all and any manœuvres of the engines to be carried out without fear of accident. But as a sudden variation in the speed is liable to produce priming, which may be accompanied by dangerous lowering of the water-level, all abrupt changes in the speed of the engines should be carefully avoided unless absolutely necessary.

§ 4. DISADVANTAGES OF TUBULOUS BOILERS.

168. *Danger Consequent upon Irregularity of Feed.—Distinctions between Various Types of Boilers.*—Although tubulous boilers have undeniable advantages when employed for general, or, more particularly, for naval purposes, their advantages are partly counterbalanced by corresponding disadvantages.

It is entirely in their management that difficulties are encountered, and we must now turn to consider them.

On account of the small quantity of water which they contain, tubulous boilers require most careful attention to the feed-supply. A boiler of 55 sq. ft. of grate, working under forced draught, can evaporate 12 tons of water per hour. If the separator up to the working level contains only 1 ton of water, an interruption in the feed-supply would empty it in five minutes; the fall of level in the tubes would then be extremely rapid. The top drum is, as a rule, not in contact with the hot gases, but with forced draught the tubes are exposed to temperatures capable of fusing the steel. The maintenance of the water-level and the management of the feed require therefore very careful attention. In large ships, where several boilers are fed from a common feed-pipe, the adoption of automatic feed-regulators is a wise and in some cases a necessary precaution.

The dangers resulting from shortness of water vary according to the type of tubulous boiler. If the tubes are nearly horizontal, they will be either full or empty, according to the level of the water. On the other hand, if the tubes are vertical, or nearly so, none of them can be completely emptied, so long as a small quantity of water remains in the boiler. Boilers with free circulation come under the first heading, and those of the Collet type are particularly exposed to trouble in this direction should the feed-water fail. Boilers with accelerated circulation fall under the second heading. Except in the case of an extraordinarily low water-level each tube will be filled with an emulsion of steam and water, or of steam which, towards the upper end, may become partially superheated, but the presence of which will be sufficient to keep the tube from overheating. This fact has rendered the use of automatic feed-regulators less important than they were thought to be in the early days. In fact, without serious

inconvenience, the top drum might almost be a steam drum, as in the case of the Belleville boilers, or the tops of the tubes might, without injury, be above the water-level, as in the case of the early Thornycroft boilers.

169. *Necessity of using Pure Feed-Water.* — The tubes of tubulous boilers can only stand the intense heat to which they are exposed when cooled by a continuous circulation of water. Any obstructed tube means a burnt tube; any tube in which a deposit has commenced to form will shortly become an obstructed tube, because the deposits tend to increase due to the retardation of the circulation. Tubulous boilers, therefore, necessitate the use of very pure water, and the use of sea-water must be rigorously avoided, and all the fittings used to purify the feed-water must be kept in good working order.

In conclusion, we may say that the disadvantages of tubulous boilers lie mainly in the danger that may result from their breaking down, but this can be minimised by incessant and careful inspection.

Tubulous boilers should on no account be used on board vessels where the loss of feed-water, during its cycle in passing to and from the engines, exceeds 5 per cent., and where this loss is made up from the sea, and more especially if the engineer in charge thinks it beneath his dignity to keep a sharp lookout on the stokehold.

There is a fatal prejudice on the subject of boilers which has to be overcome. They are by no means of such simple construction as is often supposed, nor is their management so easy. At present there is no problem in the design and construction of engines which approaches in difficulty those encountered in boiler design; there is no post in the engine-room which necessitates so much constant care, and at times so much ability and presence of mind, as is required for the proper management of the boilers.

§5. COMPARISON OF DIFFERENT TUBULOUS BOILERS.

170. *Comparison of Belleville, D'Allest, and Niclausse Boilers.* —The general comparison of all types has been dealt with in the preceding sections; but a few more exact particulars may be added with advantage.

The three types of boilers, Belleville, D'Allest, and Niclausse, are in actual service in three similar cruisers, the *Bugeaud*, the *Chasseloup-Laubat*, and the *Friant*, and detailed information from actual working should be forthcoming. The three engines are, moreover, nearly identical, and were built in the same workshops; the number of expansions $\left(\frac{D^2}{i\,d^2}\right)$, which are equal to the quotient of the volume of the low-pressure cylinders, divided by the volume of the high-pressure cylinders at the point of cut-off, are the same.

The principal particulars are :—

—	Belleville. — *Bugeaud.*	D'Allest. — *Chasseloup-Laubat.*	Niclausse. — *Friant.*
Grate area . . . . sq. ft.	758	732	783
Heating surface . . . . „	21,593	19,451	22,928
Working pressure . lbs. per sq. inch	242	213	213
Total weight of boilers with water as calculated by the builders } tons.	359·2	341·5	329·7
Total finished weight when made, as given by dockyard . . } „	407·4	361·2	363·2
Number of expansions $\frac{D^2}{i\,d^2}$ . . .	7·41	7·41	7·41

The official reception trials gave the following results :—

—	Belleville. — *Bugeaud.*	D'Allest. — *Chasseloup-Laubat.*	Niclausse. — *Friant.*
1. *Speed trials.*			
Boiler pressure . . lbs. per sq. inch	224	185	195
Pressure at the engines „ „	162	160	163
Expansions $\frac{D^2}{i\,d^2}$	7·2	7·34	7·63
Horse-Power developed	9,439	9,714	9,438
Coal-consumption per square foot of grate lbs.	26	23·9	25
Coal-consumption per horse-power	2·06	1·78	2·03
2. *Coal-consumption trials.*			
Boiler pressure . . lbs. per sq. inch.	194·7	171·5	180
Pressure at the engines „ „	128·7	135·6	141·6
Expansions $\frac{D^2}{i\,d^2}$	12·6	12·59	12·4
Horse-Power developed	3,732	3,536	3,607
Coal-consumption per square foot of grate lbs.	9·46	10·85	10·25
Coal-consumption per horse-power . „	1·367	1·48	1·491

The working of all three types of boilers gave entire satisfaction, the Niclausse boiler making a specially favourable impression, as it was not so well known, and consequently the excellent results obtained were not expected.

Taking the consumption per hour and per horse-power of the Belleville boiler in the two trials as unity, we obtain the following Table :—

—	Belleville.	D'Allest.	Niclausse.
Speed trials	1	0·858	0·905
Coal-consumption trials	1	1·083	1·089

As regards coal consumption, the Belleville boiler has the advantage when under easy firing; its good qualities under these conditions have long been recognised.

With hard firing the Belleville is about 20 per cent. less efficient than the D'Allest boiler, and about 10 per cent.

less than the Niclausse boiler. These results are what would have been expected; but they have been rendered more striking by the fact that the fires were hardest pushed on the boiler least adapted for it.

On account of the absence of circulation, the steam in the Belleville boilers has to make its way through almost dead water, and ought to give rise to more foaming on the surface and more priming. Further, the transmission of heat by convection is imperfect. The combustion-chamber of Belleville boilers is also wanting in height. These are the probable reasons for the inferiority of the Belleville boiler at high rates of working; they are both avoided in the D'Allest, and the first is overcome in the Niclausse boiler. The D'Allest boiler cannot stand hard firing, by reason of its general construction, which restricts the free expansion of the tubes.

In order to arrive at a more definite conclusion, it would be necessary to push the three boilers up to their fullest possible capacity in evaporative trials, in which the feed-water and the dryness of the steam would be measured. The engines could not be worked, as it would not be possible for them to use all the steam produced. The claims of all three makers (and particularly of M. Niclausse), that their boilers are capable of working at higher rates of combustion than those realised during the trials of the three above-named cruisers, would thus be substantiated.

Since the reception trials, a boiler on the *Friant* has had a slight mishap through a badly welded tube. An inspection made, without giving previous notice, on the occasion of change of engineers on board this boat, revealed the fact that the lower ends of several of the tubes were clogged with deposit.

Daily experience confirms the opinion that the Belleville and the Niclausse boilers will stand rough usage and varying temperatures equally well, and both offer facilities for taking

apart and repairing, but in this latter respect the Niclausse boiler is superior to all the others, though it needs particular attention being paid to proper upkeep. The D'Allest boiler, the construction of which more nearly approaches that of a tubular boiler, has not quite the same facilities in this direction.

171. *Comparison of Du Temple and Normand Boilers with the preceding ones.* — Amongst the types having accelerated circulation, the Du Temple and Normand boilers are the only ones of which any lengthened experience has been obtained in the French Navy.

These boilers have never been subjected to a comparative trial with the three types considered in the preceding paragraph; but from a comparison with locomotive boilers, which they have replaced on board French torpedo-boats, it might be concluded that they have, at high rates of combustion, a marked general superiority, both as regards good combustion and the utilisation of the heat. It is an established fact that they may be worked at a rate of combustion of 40 lbs. per square foot of grate with greater security than boilers with limited, or even free circulation at 30 lbs. Remarkable economical results were obtained from the *Forban* (see Table, paragraph 40), and these results have since been repeated in a number of subsequent tests.

The Du Temple and Normand boilers are inferior to the preceding ones, especially to the Niclausse, as regards facilities for cleaning the heating surfaces, inspection, taking apart, and for repairs. It is found that they have disadvantages as well as advantages when applied to large ships. The proper cleaning of the tubes has an enormous importance on the coal consumption, especially on a long commission. This is a point which must be borne in mind when comparing different types of boilers, and is one in which boilers of the Du Temple type are particularly weak.

All the boilers with horizontal tubes are liable to suffer from the want of head-room over the grate, or of sufficiently roomy combustion-chambers. The hot gases enter the tube before they are properly burnt, and smoke and deposit of soot are the consequence.

It was this fact which largely led M. Joessel to abandon the use of this type of boiler. Distinct progress has been made in this direction since then, by the use of the Belleville economisers, which, though they have reduced the smoke, have not overcome the deposition of soot on the tubes. The cleaning of the tubes in this class of boiler, though a comparatively simple operation, is a necessary and frequent one. Boilers with nearly vertical tubes, forming an arch over the furnace provide the necessary space to ensure proper mixture of the gases, particularly so when the course of the gases is carefully arranged. Mr Weir, as noted in paragraph 148, has practically overcome the smoke difficulty and the deposition of soot, and thus rendered tube-cleaning when under way unnecessary.

Whatever may be the inherent advantages and disadvantages of the two systems, and upon which engineers are not yet agreed, the adoption of boilers with accelerated circulation is an accomplished fact for torpedo-boat destroyers, scouts, and small cruisers, in fact, in all vessels of moderate dimensions, necessitating a high speed.

172. *Combination of Tubulous and Cylindrical Boilers.*— In the French Navy, and in the Messageries Maritimes, the problem of the complete substitution of cylindrical boilers by tubulous boilers has been boldly faced. Elsewhere great caution has been shown, and a partial substitution first made, both kinds of boilers being placed in the same stokehold. Such has been the solution adopted in America, for the Ward boilers in the *Monterey*; in Germany, for the boilers of the ironclads *Kaiser-Friederich III.*, and *Ersatz-Friedrich-der*

Grosse, and on the cruiser *Ersatz-Leipzig*, and a choice is to be made later on between the four types—Belleville, Niclausse, Dürr, and Schulz-Thornycroft, now on trial in four cruisers. In Holland this solution has been tried on board the cruisers *Holland*, *Zieland*, *Friesland*, which carry two cylindrical boilers and eight Yarrow boilers, and lastly upon a training frigate of the Argentine Republic, which is fitted with Niclausse and cylindrical boilers.

M. Sigaudy has also fitted on board a tug at Bayonne a Normand boiler combined with a cylindrical boiler.

This partial adoption of the new boilers would appear not to have given rise to any inconvenience. The two kinds of boilers, connected to a common steam-pipe, work well together.

The combination of cylindrical and tubulous boilers has not always been an entire success. In America practice seems to tend towards the exclusive use of tubulous boilers, either of the Niclausse or Babcock & Wilcox type as the result of the trials on the *Monterey* and *Atalanta*. In Holland three cruisers of the *Utrecht* type, and three cruisers of the *Köningin-Regentes* type, which were built immediately after the *Holland* type are fitted entirely with Yarrow boilers. In Germany, however, the system of fitting two-third cylindrical and one-third tubulous boilers has been continued on the new battleships, but tubulous boilers alone have been fitted on the cruisers.

CHAPTER XV

WEIGHT AND SPACE OCCUPIED BY TUBULOUS BOILERS

173. *Table of Weights.* — In calculating the weights of tubulous boilers, the same division and grouping of the constituent parts has been adhered to as for cylindrical boilers, in order to render a comparison of details possible.

The weight of the petroleum burners and other accessories for mixed firing has been added on the new ships arranged for mixed firing. These accessories have been added under heading II. "Elements depending on the rate of working."

As the stress on the materials is very slight in the greater number of the constituent parts, and, above all, in the tubes which constitute the principal portion of a tubulous boiler, considerations of pressure are hardly necessary in determining the thickness; the question of durability is of greater importance. The classification followed, although quite logical for cylindrical boilers, is therefore rather arbitrary for tubulous boilers. In particular, it may be remarked that the ratio of weight, P_1, to the working pressure, Π, is not of much value, but as the pressure, Π, is nearly the same for all the different types of boilers there is no risk that comparisons based upon this ratio would be inexact.

It was only possible to prepare tables as detailed as those given, by borrowing from various sources, and often by trespassing on the kindness of the makers. A great many of the figures, which are taken from the actual finished weights in the shops, are more exact than those supplied by the contractors with the drawings; but it was not possible to obtain finished weights in all cases.

174. *Space Occupied.*—A Table, similar to that compiled for tubular boilers (Chapter X.), is subjoined, and gives the space occupied by the various tubulous boilers referred to in Table I.

TABLE II.

Type of Boiler.	Number of furnaces.	Name of Vessel.	Horizontal Projection in square feet of the Boiler. c	Horizontal Projection in square feet of the Grates. g	Ratio $\frac{c}{g}$
Belleville	1	*Alger*	50·76	31·4	1·616
		Latouche-Tréville	70 01	43·34	1·616
		Bugeaud	54·85	34·41	1·594
		Bouvet	59·9	35·49	1·688
		Galois	89·9	57·32	1·568
		Marseillaise	70·55	44·79	1·575
Oriolle	2	*Zouave*	54·2	31·4	1·726
	1	Torpedo-boats, 161 to 163	41·94	24·2	1·731
D'Allest	2	*Jemmapes*	138·4	80·66	1·715
		Chasseloup-Laubat	128·7	68·81	1·87
		Cassini	133·35	77·83	1·713
		Carnot	167·8	90·32	1·857
Collet-Niclausse	1	*Elan*	44·55	21·4	2·081
		Friant	266·1	183 25	1·452
		Henri IV.	63·67	42·01	1·515
Du Temple	1	*Dragon*	76·02	40·65	1·87
		Averne	75·7	38·18	1·983
		Torpedo-boats, 195 to 200	118·62	45·17	2·625
Du Temple-Normand	1	*Flibustier* (1900)	92·17	33·34	2·765
Normand	1	Torpedo-boats, 148 and 149	122·17	35·7	3·421
		Torpedo-boats, 182 to 185	118·07	38·72	3·049
		Forban (1901)	119·05	44·1	2·699
Normand-Sigaudy	1 double-ended	*Château-Renault*	239·81	96·48	2·485
		Dunois and *Lahire*	195·2	65·17	2·995
Du Temple-Guyot	1	*Jeanne d'Arc*	101·64	46·36	2·192
Thornycroft	1	*Véloce*	102·06	37·96	2·688
		Coureur	101·54	38·07	2·667
Yarrow	1	Torpedo-boat, C.	27·53	12·26	2·245

NOTE.—In boilers of the Du Temple type, the rectangle formed by the lower drums has been taken as the floor space occupied, and therefore in reality the actual space occupied is somewhat less than that given by the figures in the above Table

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PART IV.

CHAPTER XVI.

BOILER MOUNTINGS AND OTHER FITTINGS.

175. *Classification of Boiler Fittings.*—The parts or fittings classed under boiler mountings are very various, and are put to very different uses. Some of them form part of the boiler itself, or at least are fitted to the boiler. Among such may be named the manhole doors, furnace fittings, uptake and funnel. Others again are quite distinct from the boiler, and amongst such may be included the stop-valves, feed-check-valves, safety-valves, etc. Others are perfectly independent of the boiler, and may be placed at some distance from it. Amongst these are fittings directly dependent upon the engine, and only indirectly so upon the boiler. For instance, the condenser, though properly a part of the engine, of which it increases the power, is nevertheless an essential fitting for the boiler, as it secures the boiler being fed with fresh water. In this category all the fittings relative to the feed-water may be included. We have already described several fittings which need not be again enumerated here, such as fire-bars, petroleum burners, forced draught fittings, feed-heaters, air-heaters, and so forth.

The study of boiler fittings and their construction might

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be dealt with at great length, but a short description of them, and a statement of the conditions they are designed to fulfil, must suffice here. Their construction needs great care, and none of the fittings can be ignored with impunity.

176. *Self-jointing Manholes.*—The manholes and their fittings are almost the only accessories that form part of the actual boiler-shell.

Formerly, with rectangular boilers, the manholes might be placed in almost any convenient position; those to gain access to the steam space were usually placed on the crown of the boiler. With the present higher pressures the number and size of the openings are reduced, and to obviate, as much as possible, cutting any openings in the

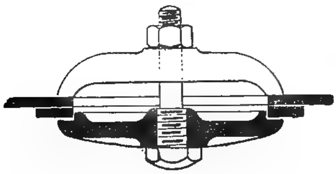


Fig. 241.

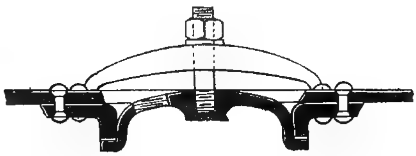


Fig. 242.

circular shell, the manholes in cylindrical boilers occasionally are placed on the boiler fronts, and in tubulous boilers upon the two ends of the cylindrical collectors or steam drums. These manholes are strengthened throughout their circumference by a stiffening ring of plate, or, better still, angle-iron, to compensate for weakening the shell plate, and to give the stiffness necessary for drawing up the joint. Where boilers of the Belleville, Niclausse, and Babcock and Wilcox, or similar types, in which the steam drums are usually arranged at right angles to the length of the grate, are built in "battery," the steam drum ends are too close together to allow the manhole doors to be fitted on the ends, and these doors have to be placed on the cylindrical portion.

The door is always self-closing; that is to say, held up to the joint by the boiler-pressure itself. It is a forging or stamping placed inside the boiler, and held in position by a screwed bolt passing through a bridge or "dog," applied to the outside of the boiler. Fig. 241 shows a type of manhole and door of an early design; Fig. 242 shows the present type, which exhibits a considerable advance on the former, on account of the increased stiffness of the edges and the greater facility for machining the same.

177. *Furnace and Ashpit Doors.*—The furnace doors are

MARTIN FURNACE DOOR.

Section on A B.

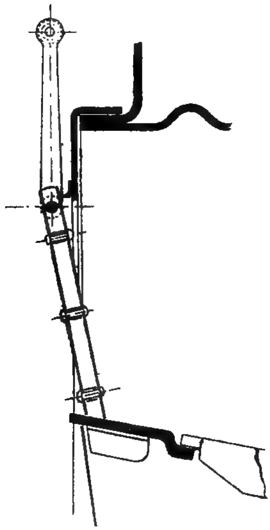


Fig. 243A.

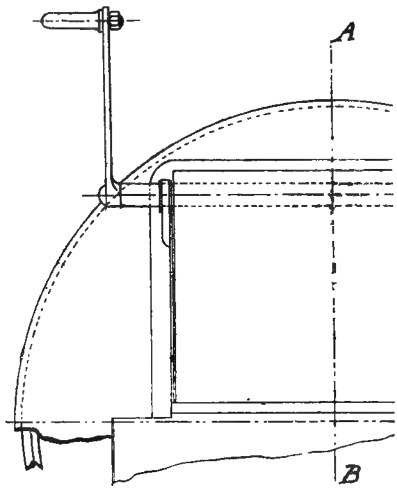


Fig. 243.

pierced with holes for the passage of air, and fitted on the inside with perforated baffle-plates to prevent overheating. In French naval practice the old style of door, turning upon vertical hinges and closing with a latch, has now been superseded by the "Martin" door, hung upon a long horizontal hinge and closing automatically.

The object of this change is to reduce, as much as possible, the length of time the doors are open when stoking.

In British naval practice the furnace door turning on vertical hinges is still the one most frequently fitted. In small tube water-tube boilers the axis of the hinge lies in a

Arrangement of Furnace Door of Torpedo-boat Boiler.

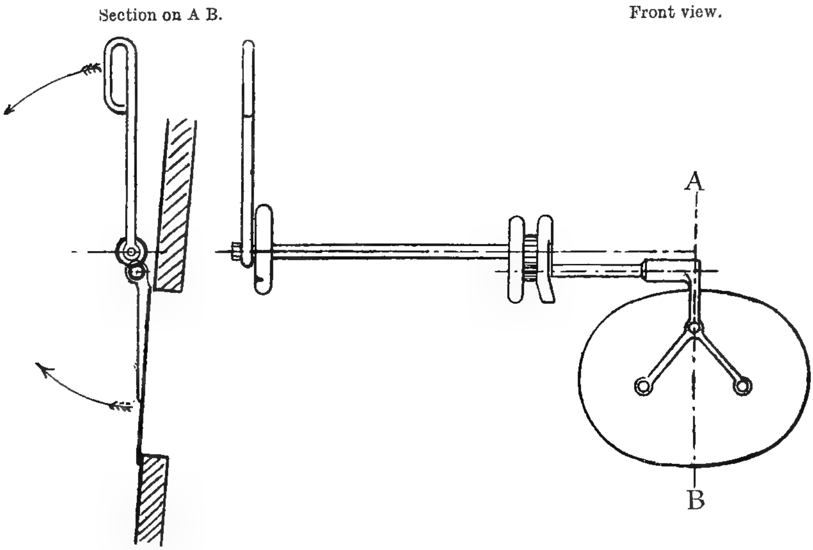


Fig. 244A. Fig. 244.

vertical plane, parallel to the boiler front, but inclined slightly to the vertical in a plane perpendicular to the boiler front. The door, when opened, thus tends to close by its own weight. In ships fitted to burn liquid fuel the Martin type of door is more convenient than the old type, as it allows more space on either side of the door in which to place the liquid fuel burners, and they are not likely to be damaged by the opening and closing of the door.

The new doors open inwards, and tend to close by their own weight, so that, should an escape of steam take place in the furnace, the rise of pressure only tends to close them more

firmly. Two stokers are needed for firing, as the doors require to be held open by hand. This is not a serious disadvantage, because the fires are never charged together, and it does not really entail any extra work.

ASHPAN DOOR OF TORPEDO-BOAT BOILER.

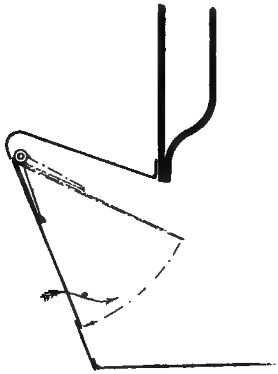


Fig. 245.

The ashpit doors regulate the supply of air; they are usually constructed with two wings, each one having a small opening, which is closed by a "butterfly" shutter.

It is a simple matter to construct the ashpit doors in such a manner as to make them close automatically, to act as a safety device in the event of an escape of steam. This arrangement is compulsory on board French torpedo-boats having locomotive boilers, and is now becoming general.

178. *Funnel Casings and Funnel Covers.*—With the older types of tubular boilers having very thick shells, to which the smoke-boxes were solidly bolted, the funnels were provided with a seating sufficiently strong to meet all requirements; they rose up through their hatchways, and expanded freely, without more attention being necessary than to take care the stays were sufficiently slack to allow of expansion on lighting up.

The funnel casings are fixed, the one to the hull, the other to the funnel; there must be contact, but no joint, between the hull and funnel portions, and they must always be able to slide freely one upon the other; no difficulty has been experienced in this arrangement, either in construction or working. This simple method is the one most frequently adopted, especially on passenger-vessels. With closed stokeholds, the adoption of forced draught introduces a slight

complication by necessitating the use of some closing device in the casings.

On torpedo-boats, the top of the casing is simply closed by an angle-iron ring, or flanged plate, on the flange of which the funnel slides when expanding. But, on ships where the casings have to serve for the escape of the heated air, it is necessary to fit shutters (Fig. 247).

The introduction of tubulous boilers, having casings of thin plates not strong enough to stand heavy strains, has necessitated some modification of the older type, and thrown upon the hull itself the duty of supporting the greater part of

TORPEDO-BOAT FUNNEL.

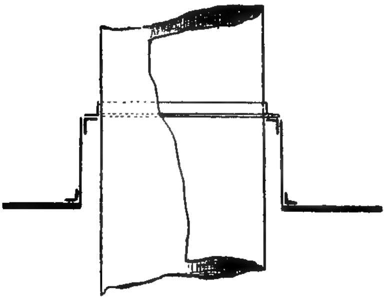


Fig. 246.

SFAX.

FUNNEL CASING WITH SHUTTERS.

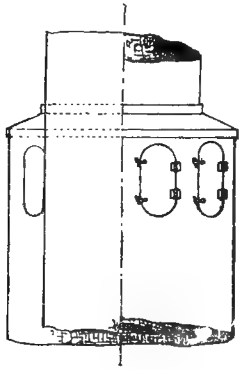


Fig. 247.

the weight of the funnel, and also the tension of the stays. In modern practice the boilers only support the lower portion of the funnel, chiefly the portion where the greatest expansions take place. The upper part of the funnel, with the whole of the casing, forms a framework riveted to the surrounding edges of the hatchways. The two parts of the funnel thus divided slide over one another, and are united by a very simple expansion joint packed with asbestos or silicate cotton. The figure 248 shows an arrangement of this description adopted on the *Friant*.

The whole of the upper part of the funnel thus becomes, strictly speaking, an accessory of the hull and not of the boiler.

FRIANT.

FUNNEL STUFFING-BOX.

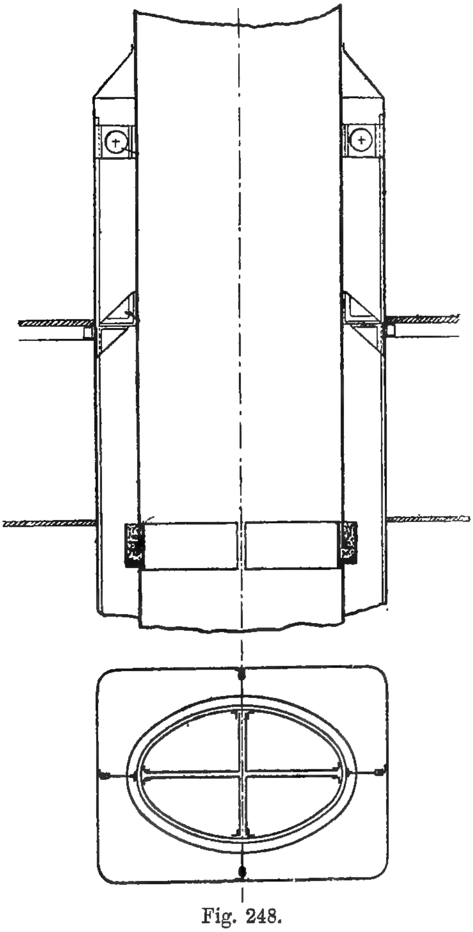


Fig. 248.

The top of the funnel should be closed by a cover during periods of inaction or when laid up, to keep out rain and moisture; the soot, when dry, constitutes a good preservative

coating, but when damp becomes, on the contrary, an active destructive agent to the plates. On the older ships it was thought sufficient to provide canvas coverings, which were placed in position by being suspended from a stay. In the French Navy funnel covers of thin plate are now provided,

CHARLES MARTEL.

FUNNEL COVER.

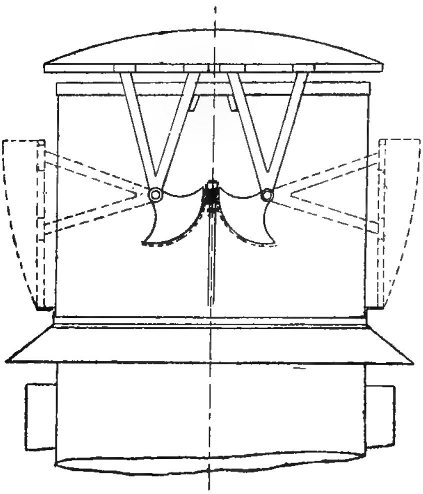


Fig. 249.

turning on a hinge, and worked from the deck by means of chains or rods, as shown in Fig. 249. A flexible roller shutter of thin plate has also been tried, but its excessive weight has caused it to be abandoned.

Canvas funnel covers are now adopted in all new ships of the British Navy.

CHAPTER XVII.

BOILER STEAM FITTINGS.

179. *Pressure-gauges and Sentinel-valves.*—Bourdon pressure-gauges are those most commonly used; they are most simple in their manner of working, and the readings are uniformly reliable; they are easily fixed, but care should be taken to place them in a well-lighted and convenient position.

In the French Navy it is considered essential that an automatic signal should be conveyed to the stokehold when the pressure approaches that at which the safety-valves are adjusted to blow off. This duty is fulfilled by a small safety-valve, termed a "sentinel" valve, which is fixed on the boiler-front, having its blow-off pipe carried into the stokehold. In the French Navy this valve has a diameter of only $\frac{3}{16}$ of an inch. The valve seat is flat, and the load is adjusted by means of a spring, in the same manner as the main safety-valve. The valves are also closed up in such a manner that the load on them cannot be tampered with. Under these conditions the guarantee of their reliable action is precisely the same as for the main valve. The sole object of these sentinel-valves is to prevent the lifting of the main safety-valve through unforeseen excess of pressure. In the American Navy these sentinel-valves, instead of being loaded by a spring, are directly loaded with weights placed upon the valve spindle. Many engineers have more confidence in the direct action of weights than in springs. On the other hand, the weights, although

having a decided advantage on shore, have at sea the great disadvantage of allowing the valves to blow off at varying pressures when the ship is in a rough sea, due to the inertia of the weights; this has led to direct weights for safety-valves and sentinel-valves being abandoned in the

BOUVET

DOUBLE SAFETY-VALVE.

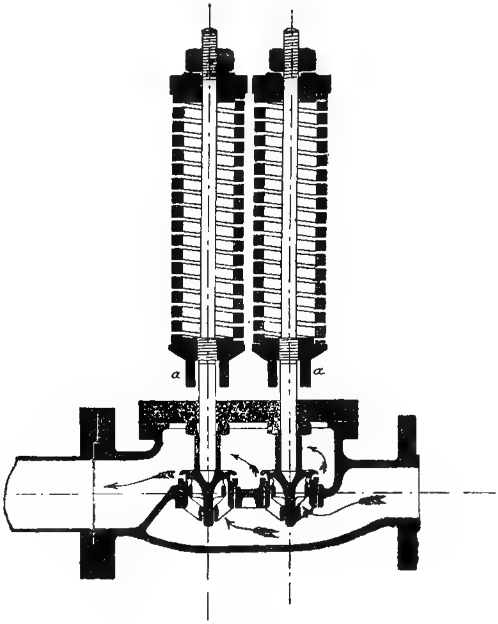


Fig. 250.

a. Easing levers.

French Navy. The use of sentinel-valves was discontinued in the British Navy about twenty years ago.

180. *Safety-valves.—Calculation of their Area.*—Although for regulating the water-level it is generally considered sufficient to rely upon the man in charge adjusting the feed by hand, for the pressure, on the contrary, it is absolutely necessary to have an automatic regulator, and this is fulfilled by the safety-valve. The safety-valves of marine boilers

were, years ago, loaded by means of a counter weight acting upon a lever ; several valves of this type are still in use. The variations in the weight tending to keep the valves shut, which we have alluded to above, led to the counter weight being replaced by two steel spiral springs. The heads of the two springs pull on a cross-bar, pressing directly upon the valve spindles; stop rings are fitted in such a manner as to prevent the springs being strained beyond the tension corresponding to the boiler pressure.

Arrangements are always made to allow the safety-valves being eased off their seats by hand, at all pressures. With the older types the counter weight was eased by means of a pedal attachment worked by a screwed rod. With spring safety-valves the easing gear is arranged so that the cross-bar or yoke is lifted by means of a lever and a screwed rod. The hand-easing gear must always work freely and quickly. Upon all ordinary occasions it must also be capable of easing the valves slowly and gradually, because any abrupt fall of pressure is very liable to start priming; on the other hand, should an accident occur, it may be necessary to be able to lift the valve with all possible speed.

The waste-pipe from the safety-valves is, in French practice, frequently led into the condenser, and not into the open air. This causes a slight complication in the pipe arrangement, but is more than compensated for by important advantages: the loss of fresh water is obviated, and also the deafening noise of the steam escaping from the waste-pipe above the deck; besides, in case of leaks, the outlet into the condenser prevents the steam from getting into the stokehold. It has the disadvantage, however, that any leakage from the safety-valve is not readily apparent. The same result as regards prevention of waste of fresh water is obtained in British practice by fitting a "silent blow-off" consisting of a pipe with an ordinary screw down valve in it connecting the main steam pipe with the condenser.

The area of escape of the valves must be sufficient to allow free passage, under full working pressure, to all the steam the boiler can produce when the engines are stopped. The Board of Trade rules require an evaporation trial lasting twenty minutes, with the fires pushed and as little feed as possible. In France, however, it is considered sufficient to require a minimum area, determined by empirical formulæ, of which many exist.

The rule usually adopted in France was established by supposing the rapidity of escape to be determined by the formula

$$(1) \qquad V = \sqrt{2gH}$$

in conjunction with the expression

$$(2) \qquad H = 10.33 \frac{1000}{8} p_0$$

in which H is the height of the gaseous column, δ the weight of a cubic metre of gas in kilogrammes, p_0 the pressure in atmospheres; then according to the laws of Mariotte and Gay-Lussac for gases,

$$(3) \qquad \delta = 1.293\,(p_0 + 1)\frac{1}{1 + a\,t}.$$

where $a = 0.00365$.

Ω being the sectional area of the orifice, the volume flowing per second is ΩV, and its weight is

$$(4) \quad \rho = \Omega V \delta = \Omega\delta \sqrt{2g \times 10.33 \frac{1000}{\delta} p_0} = \Omega\sqrt{2g \times 10{,}330\, p_0\, \delta}$$

or by substitution

$$(5) \qquad \rho = \Omega\sqrt{2g \times 10{,}330 \times 1.293 \frac{p_0\,(p_0 + 1)}{1 + a\,t}}$$

Representing the constants by

$$M = \sqrt{2g \times 10{,}330 \times 1.293}$$

then

$$(6) \qquad \rho = M\,\Omega\sqrt{\frac{p_0\,(p_0 + 1)}{1 + a\,t}}.$$

Admitting, on the other hand, that the weight ρ of steam

produced per second is proportional to the heating surface S (in square metres), then M_1 being a new constant,

$$(7) \qquad M_1 S = M \Omega \sqrt{\frac{p_0 (p_0 + 1)}{1 + at}}$$

$$(8) \qquad \Omega = \tfrac{1}{4}\pi D^2 = \frac{M_1}{M} S \sqrt{\frac{1 + at}{p_0 (p_0 + 1)}}$$

from which M_2 being a factor containing only constants, is deduced—

$$(9) \qquad D = M_2 \sqrt{S} \sqrt[4]{\frac{1 + at}{p_0 (p_0 + 1)}}$$

where approximately, in modifying the constant to bring in the factor $1 + at$ assumed to be constant, and in replacing $p_0 + 1$ by p_0 then

$$(10) \qquad D = M_3 \sqrt{\frac{S}{p_0}}.$$

The following empirical formula has been arrived at by experience, the pressure being stated in atmosphere—

$$(11) \qquad D = 1.3 \sqrt{\frac{S}{p_0 + 0.588}}$$

Calling P_0 the absolute pressure $p_0 + 1$, the formula may be written—

$$(12) \qquad D = 1.3 \sqrt{\frac{S}{P_0 - 0.412}}$$

As a precaution, the diameter D is doubled, thereby quadrupling the area, which gives the formula at present in general use in France—

$$(13) \qquad D = 2.6 \sqrt{\frac{S}{P_0 - 0.412}}$$

thus ensuring a rapid fall in pressure when the valves are opened.

The formula (13) was employed in the French Navy for a long time, and is still sometimes used; but, independently of the small amount of value to be attached to the theoretical principles upon which it is based, it gives the value of D in

terms of the heating surface, which, in marine boilers, represents very inadequately the power of steam production.

At the present time another formula is in use at Indret, introduced by M. Brosser, where if ρ is the quantity of steam in kilogrammes per second escaping from an orifice of area Ω, we have—

(14) $$\rho = \Omega\ (25.5 + 144.5\ P_0),$$

or, (14A) $$\rho = \Omega\ (170 + 144.5\ p_0),$$

P_0 and p_0 being taken in atmospheres. The production of steam per second of the boiler is always approximately,

(15) $$\rho = \frac{8\ G\ C}{3600},$$

G being the grate area in square mètres and C the coal consumption in kilogrammes per hour per square metre of grate. M. Brosser thus arrives at an evaporation of eight kilogrammes of water per kilogramme of coal, a fairly accurate figure, though low for modern practice.

The equation

(16) $$\Omega\ (170 + 144.5\ p_0) = \frac{8\ G\ C}{3600}.$$

gives for the diameter expressed in metres the value

(17) $$D = \sqrt{\frac{32}{3600\pi}} \sqrt{\frac{G\ C}{170 + 144.5\ p_0}}.$$

M. Brosser assumes a constant value for C equal to 80 kilogrammes per square metre per hour, on the assumption that the forced draught can be stopped instantly when it becomes necessary to get rid of the steam. In giving C this value, and in substituting the effective pressure p_0 in atmospheres for the pressure p_1 in kilos per square centimetre, the formula becomes—

(18) $$D = 0.242 \sqrt{\frac{G}{175.61 + 144.5\ p}}.$$

Trials made at Indret have proved that the formula (18)

gives areas capable of allowing the passage of twice the amount of steam produced by quick fires and natural draught. By means of this formula the diameters of a series of valves have been determined which suffice for all sizes of boilers. It is necessary, in order to get convenient sizes, to reduce the diameter D and make the valves double, that is to say, to arrange two valves side by side having one steam inlet and escape-pipe common to both.

The method of specifying safety-valve area for British naval boilers is arrived at from the law which has been tested experimentally that the quantity of steam discharged in pounds per second through an orifice one square inch in sectional area is equal to $\frac{P}{70}$ where P is the absolute pressure in pounds per square inch.

The lift of the valve is limited to one-fortieth of its diameter when discharging all the steam which the boiler is required to produce to maintain full power. It is assumed that 20 lbs. of steam are required per I.H.P. per hour, and as a certain definite heating surface is specified per I.H.P., the quantity of steam required to be produced per square foot of heating surface is known, and hence it is possible to express the safety-valve area in terms of the absolute boiler pressure and the heating surface.

Let S be the heating surface per I.H.P., then the quantity of steam produced per square foot of heating surface $= \frac{20}{S}$ per hour or $\frac{20}{3600\ S}$ lbs. per second. If A be the sectional area of flow required, the quantity of steam discharged per second equals—

$$\frac{A\ P}{70}.$$

But the lift being limited to one-fortieth of the diameter, the area of flow is only one-tenth the area of the safety-valve orifice. Hence the area of the safety-valve orifice

(or orifices) A is such that $\frac{A_1}{10} = A$. Equating the rates of generation and discharge of the steam we have

$$\frac{A_1 P}{700} = \frac{20}{3600 S},$$

or,

$$A_1 = \frac{14,000}{3600 \times P \times S},$$

which gives the disc area of the safety-valves per square foot of heating surface. Thus with a boiler pressure of 300 lbs. absolute and with an allowance of 3 square feet of heating surface per I.H.P. (*i.e.* $S=3$)

$$A_1 = \cdot 00433.$$

Therefore a boiler with one-thousandth square feet of heating surface under the above conditions would require a disc area of safety-valve of 4.33 square inches, or a valve about $2\frac{3}{8}$ inches diameter.

It is to be noted that in naval boilers S varies with the type and also with the nature of the draught; a boiler with forced draught having naturally a smaller allowance of heating surface per I.H.P. than one with natural draught.

181. *Safety-valves with High Lift.*—It is assumed in the preceding formulæ that the lift h of the valve gives an area of escape, $\pi D h$, at least equal to the area $\frac{1}{4} \pi D^2$, that is to say,

$$h \geqq \tfrac{1}{4} D.$$

When the lift of the valve has been determined in such a manner as to fulfil this condition, it is a somewhat difficult problem to obtain the maximum lift and at the same time ensure that the pressure does not rise sensibly above p_0, since the springs being short, their tension increases very considerably with the lift of the valve. The problem is solved by utilising the reaction of a jet of steam projected at great

velocity against an obstacle which deflects it. Fig. 251 shows the form of valves adopted at Indret. In addition to the dynamic reaction exercised against the valve and its flange, as soon as the steam commences to escape a certain static effort is exercised on the flange. The extra tension on the spring is thus counterbalanced, and the valve gets its full lift.

The Figs. 252 and 253 represent other forms of valves where, to arrive at the same result, the dynamic action alone is made use of.

The actual valve face is not acted upon by the pressure when the valve is shut but is subjected to it when the valve

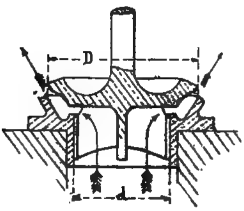


Fig. 251.

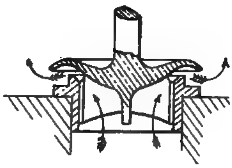


Fig. 252.

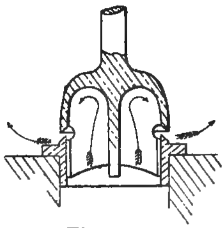


Fig 253.

lifts; there are therefore two pressures, the pressure of opening and the pressure of closing. Formerly, with the conical seats, the pressure was calculated on the larger diameter, the working pressure being the pressure at which the valves would close; the ratio of the two surfaces was equal to 1.17, and therefore boilers calculated for a working pressure of 32 lbs. should not have blown off until a pressure of 37 lbs. was reached; as a matter of fact, the valves lifted at about 35 lbs., commenced beating, and were barely closed when the pressure had fallen to 32 lbs. At present the weight on the springs is calculated from the small diameters and made equal to 1.05 sp_0; that is to say, greater by 5 per cent. than the nominal working pressure. The valve seat is flat; the width of the seating is reduced to about $\frac{3}{64}$ths of an inch, or $\frac{3}{32}$nds of an inch at most, so as to make the boring or grinding

in of the seats and valves an easy matter; it also reduces the difference between the opening and closing pressures, and consequently reduces the amount of beating on the seats. The grinding up of the seats and valves must always be done with great care. Formerly, with the large conical valves, it was necessary to turn and bore them while hot, on account of the deformation of the valve chests, due to expansion, and absolute tightness of the valve was very rarely realised in practice. Safety-valves must always be under careful supervision; they should be eased from time to time in order

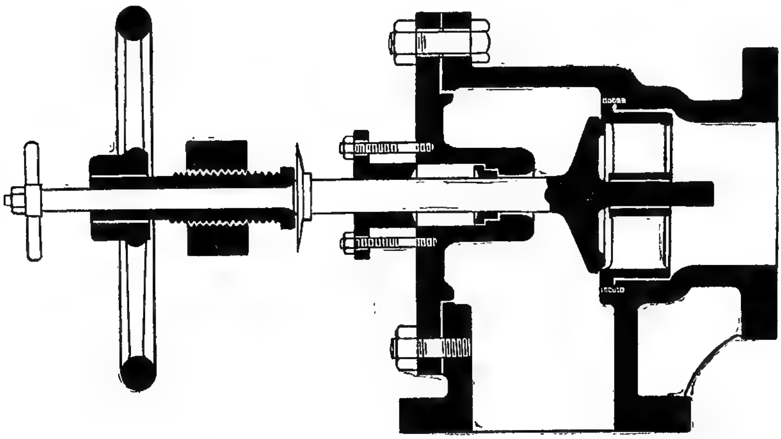


Fig. 254.

to get rid of dirt and scale which otherwise might cause the working pressure to be exceeded by several pounds. The valves, as well as the seatings, are of gun-metal, in order to avoid trouble through oxidation. The valve chest itself is either of cast iron, or, preferably in modern practice, of cast steel.

182. *Stop-valves.—Sluice or Regulating Valves.*—The stop-valves are fitted upon the boiler itself, and are designed to control the passage of the steam from the boiler to the whole of the steam piping. Similar valves are fitted upon the

communication pipe leading from one boiler to another. Stop-valves must be above all simple in construction and certain and quick in action. The stop-valve should be constructed to shut automatically in the event of any considerable fall in pressure in the boiler upon which it is fitted. This arrangement is stipulated for in the Royal Navy, the type of valve being illustrated in Fig. 254. The screwed spindle regulates the lift of the valve only, and is hollow, the valve spindle passing through it.

In France ordinary stop-valves have been largely replaced by sluice- or gate-valves, as the latter are con-

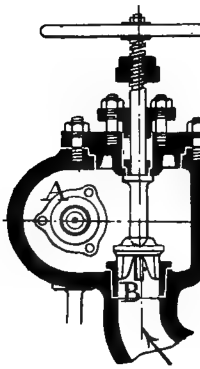


Fig. 255A.

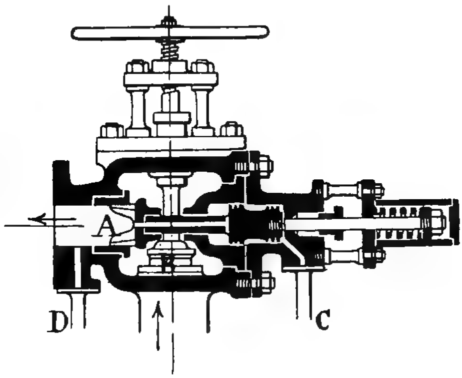


Fig. 255.

sidered somewhat tighter. Since 1896 the boilers constructed at Indret have been fitted with sluice-valves, having on a prolongation of the vane or gate an independent valve which lifts automatically as the pressure in the boiler rises, and shuts in a similar manner when the pressure falls. This arrangement is now being generally adopted.

In order to meet the case of an accident, whether in the boiler itself, or in a neighbouring boiler, or in the piping or engines, Mr Hutcheson has brought out the valve shown in Fig. 255, in which, besides the main

hand stop-valve B, there is an additional valve A. Under ordinary working conditions, the valve A, which has the full pressure on both sides, is kept open by the action of a spring. The hollow valve-spindle carries a piston, which has the same pressure on its lower side as on the lower side of the valve. The upper side of the piston has the full boiler pressure supplied through pipe C. When the pressure on the lower side of A falls through any accident occurring in the piping or elsewhere, the difference of pressure on the piston causes the valve A to shut. The auxiliary pipe D serves to warm up the piping, raising the pressure and causing the valve A to lift from its seat before the main stop-valve is opened.

The use of this type of valve renders the ordinary automatic stop-valve unnecessary. In the case of an accident to one of the boilers, all the other boilers are immediately isolated instead of emptying themselves as they would otherwise tend to do. The engines stop, and remain stopped until the injured boiler is shut off by hand by means of its own main stop-valve. The drawback to this type of valve is that it is unfortunately somewhat complicated and not too certain in its action.

The stop-valve upon the boiler and the throttle-valve on the engines were for a long time the sole means of shutting off steam from the steam-pipes. The stop-valves, which are considerably tighter than the throttle-valves, are capable of preventing the passage of sufficient steam to move the engines, but leak enough to be troublesome when disconnecting the pipes or opening up the engines under steam.

During the last ten years it has been usual to fit a valve, similar to a sluice-valve, in addition to the stop-valve, which is capable of being wedged tightly up into its conical seating, and is perfectly steam-tight.

There are many different types of these valves, but

they all work upon the same principle; the spindle causes, in the first place, the bodily movement of the plug, then its tightening in the seat when being shut; upon opening, the first motion is the loosening of the wedge-like plug, then the movement of the whole plug. This arrangement requires great care both in the construction and fitting.

The Ciron valves (Fig. 256) are subject to an additional

CIRON VALVE.

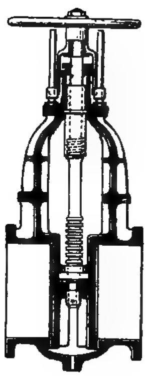


Fig. 256.

MULLER VALVE.

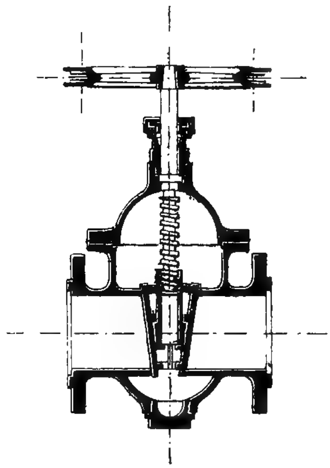


Fig. 256A.

wedging action on the first movement of the spindle, which renders the opening somewhat difficult; the Muller valve (Fig. 256A.) is a more reliable type. On account of their complication, this description of valve is not used on pipes of a lesser diameter than about 2½ ins.

Owing to the large flat faces of the conical plug and its seating, the fatigue of the material due to the steam pressure, and the strains set up by the longitudinal expansion of the steam pipes, are very great.

The earlier types, made with cast iron chests similar to stop-valves, have given rise to serious accidents, attended

in some instances with fatal results. Modern practice constructs these chests in gun-metal or cast steel, steel being used when the temperature of the steam approaches 360° Fahr. A spherical form of chest has also found favour, and great care is exercised to allow of free expansion of the piping in the expansion joints near these valves, with the result that there is a comparative immunity from accidents.

Notwithstanding these improvements, the multiplication of safety fittings is not without its inconveniences. Safety appliances, owing to the accidents to which they are themselves liable, constitute a certain element of danger. There is now a strong tendency towards simplification, and attempts have been made to reduce to two the three separate systems of piping recently fitted on some boilers, of which one set was for the main engines, the second for their auxiliary apparatus, and the third for the various separate engines, such as dynamos, winches, pumps, etc. An automatic valve which shuts off the steam in the event of any serious leak, would be a safety fitting of great value.

183. *Reducing Valves.* — Under this heading are classed a large number of apparatus in general use, apart from the engine itself, for supplying, at a lower and determined constant pressure, the gas or steam produced by a reservoir at a higher pressure.

The principle of the apparatus is as follows:—

The regulating valve is pressed from below by the engine steam, above by a resisting spring, the tension of which is set according to the working pressure desired; it is in no way subjected to the boiler pressure. The ports are sometimes arranged round a sleeve and their opening is regulated by the tension of the spring. Consequently,

as soon as the pressure falls on the engine side, the admission is increased and brings the pressure up to its normal amount.

The reducing valve works, therefore, like a kind of automatic governor, but with the advantage of rendering the speed more constant than with the ordinary governor. Taking, therefore, an engine working at 170 lbs. per square inch, and receiving, through a reducing valve, steam from a boiler working at 240 lbs. per square inch, and supposing that the production of steam accidentally falls, the speed of the engine will not be influenced as long as the pressure in the boiler does not fall below 170 lbs., that is to say, so long as the engine has not consumed $\frac{240 - 170}{240} = \frac{7}{24}$ of the steam in reserve; but irregularities in working are, generally speaking, of short duration, and do not give rise to variations in the steam production as great as the above.

The reducing-valve is an essential fitting to the Belleville boiler, the working pressure of which is generally about 240 lbs. per square inch, whilst the pressure at the engines, dependent upon the speed required, does not usually much exceed 170 lbs. They have now been in use for over twenty years on these boilers, as the small volume of the steam-collecting drum renders the engine particularly sensible to the least variation in the production of steam. Its effect is totally to neutralise the influence of variations of pressure up to 70 lbs. per square inch, which corresponds in boilers without reducing-valves, having a steam chest ten times larger, to variations of 7 lbs. only for the same irregularity of firing.

The reducing-valve, in preventing variation in the speed of the engine when the pressure rises, prevents in an effectual manner the tendency to prime, to which the Belleville boiler was for a long time especially subject. On the Belleville

boilers they are placed on the main steam-pipe, after the steam separator.

Reducing-valves, in common with all fittings that give rise to wire-drawing, produce slight superheating, equal, for saturated steam, to half the fall in temperature, dependent on the fall in pressure.

BELLEVILLE REDUCING VALVE.

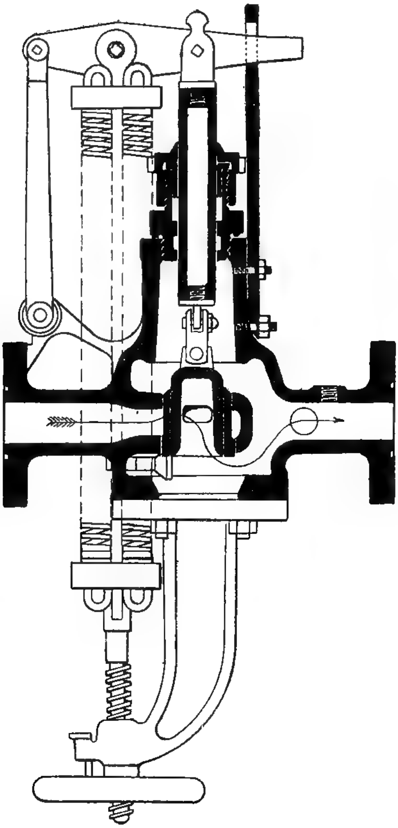


Fig. 257.

The reducing-valve is not suitable for effecting the instant changes in speed which are frequently required in the engines on a warship. Though, in the French Navy, the use of reducing valves is general in ships fitted with tubulous boilers, the tendency in the British Navy is rather to dispense with such fittings, as, though advantageous in themselves, they require considerable attention to keep in order and add to the general complication. It is doubtful whether the advantages of a reducing valve balance its disadvantages, and in some British ships fitted with Belleville boilers the reducing valves have been removed.

184. *Steam Piping.—Expansion Joints.—Steam Traps.*—Copper steam-pipes, which replaced the early cast iron piping, satisfied for a long time the requirements and

necessities of marine work. The material was easily worked, of lasting quality, and of sufficient strength to withstand the pressures and temperatures used. The failure of copper pipes of large diameter was, however, always a danger to be feared. They ruptured, not at the brazing itself, but close to it, due to local heating similarly to the fractures that occurred in welded furnaces. Copper is generally used for the exhaust pipes to the condenser. All that is necessary, in order to give them the requisite elasticity, is to form on them a bellows-shaped swelling as illustrated in Fig. 259. The adoption of high pressures has rendered the strength of copper pipes insufficient, not so much on account of the increased stress on the metal, as from the deterioration which takes place at or about a temperature of 400° Fahr.

Remedies for this failing have been sought in strengthening copper pipes either with iron rings placed close together on the pipe, or by completely binding it with steel or iron wire so arranged that the rupture at one place does not loosen the whole coil.

At present large main steam-pipes are usually made of steel, with riveted joints. The flanges, T-pieces, bends, etc., are usually made of cast steel. British naval practice as regards steam-pipes is to make them of solid drawn steel when obtainable, or failing that of lap-welded iron tubes, but with a butt-strap riveted over the weld.

The tensile strength is thus assured but the upkeep requires great attention, and their life will probably not be greater than that of the steam-collectors of boilers of similar diameter and thickness. After six years' service the results obtained are reassuring. In the tubes examined, the interior surface appeared to be smooth and a trifle oily. Despite all these precautions, a watchful eye must always be kept on the piping by the engineer.

When the main steam-piping is composed of welded

tubes, a riveted cover-joint is sometimes, as a matter of precaution, placed over the weld. Weldless drawn tubes of larger and larger diameter are daily coming into more general use.

Drawn tubes are now obtainable fitted with flanges, without the metal having been thinned down, and may be conveniently used to replace the welded on flanges. When separate flanges have to be used, the best method of attaching them is by screwing. Flanges with spigot joints are

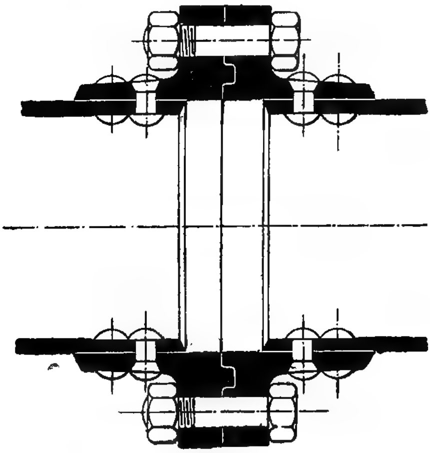


Fig. 258.

now very generally used, and Fig. 258 shows the type of joint used at Indret. Keeping the flanges tight is one of the causes that limits the pressure in water-tube boilers.

The principal cause of fatigue which has always to be feared in steam-pipes, no matter of what material they may be constructed, proceeds from expansion. This is sure to lead to ultimate rupture of the pipe unless proper means are provided to take it up.

When using copper, much was expected from the flexibility of the metal itself. On the low-pressure exhaust

to the condenser the pipes were sometimes shaped as shown in Fig. 259, but when so fitted it has been found necessary to anneal the pipes occasionally as the continual working of the bellows-shaped part of the pipe, due to expansion and contraction, causes the material to fatigue somewhat rapidly. On steam-pipes right-angled bends are more often resorted to, to give the desired flexibility, but the bends are still apt to give way at the collar, where the flange is rigidly fixed. On long lengths of straight piping, expansion joints, as shown in Fig. 260, are used, but they sometimes get jammed and fail to act, and have been the cause of fracture in pipes, the high temperature

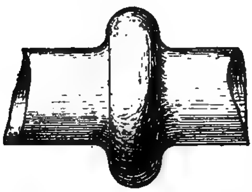


Fig. 259.

Expansion Joint.

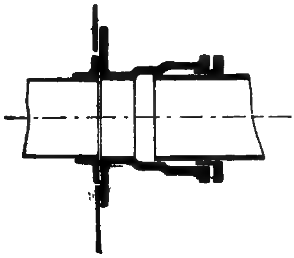


Fig. 260.

of which has rendered the metal forming them brittle. Though with steel pipes of short length and large diameter expansion joints are the only practical means of taking up expansion in the piping, it is possible in long lengths of comparatively small diameter to provide for expansion by curving the pipe to a large radius. This arrangement has been adopted wherever possible in all recent British naval vessels, and expansion joints are only fitted on the straight lengths forming the steam mains; the separate branches to the different boilers being bent to a large radius.

It is essential to secure, and make provision for, the drainage of any water that may find its way into the piping,

more especially where a change of direction in the piping might form a pocket.

In spite of all precautions taken to ensure dry or superheated steam for the engines, condensation is sure to take place in the piping, sometimes in considerable quantities, more particularly when the engines are standing, or during warming up before getting under way. If steam is suddenly admitted into the piping it meets there a mass of cold water, which causes it to condense, and to which it transfers its heat and energy. The mass of water thus put in motion, assisted by the incoming steam, may give rise to local shocks, which severely strain the piping; it may even subject the metal to stresses higher than those to which it was subjected during the hydraulic tests. This explains the rupturing of the pipes on starting up the engines, which has sometimes given rise to grave consequences. The bending over the sides of the fracture is evidence of the intensity of the shock which caused it.

The engineer in charge must always be most careful to drain his piping thoroughly before starting his engines.

185. *Separators and Superheaters.*—The fittings used to transform into dry steam the more or less wet steam that is given off by the boiler may be divided into two classes:—

(*a*) Those that dry the steam mechanically;
(*b*) Those that dry the steam by adding heat thereto.

The mechanical steam-dryers are all based upon the same principle, viz., of causing the steam to make a sudden change in its direction, thereby depositing the water, owing to its greater momentum, on the walls of the apparatus.

The separators used by the Belleville boilers, and forming an integral part of the same, extract a large amount

of water, and prevent it passing into the piping. They are described in paragraph 108, and shown in Figs. 142, 142A., 143, 143A. Separators are usually placed near the engines to stop any water coming over from the boilers, or that may have been condensed in the piping itself, from finding its way into the engines. They are almost universally employed with tubulous boilers, and often with cylindrical boilers. Separators are generally composed of a vertical cylindrical reservoir with a baffle down the centre, which forces the steam to take the course indicated in Fig. 261. The water thrown on to the sides of the vessel collects at the bottom and is drawn off by a trap or drain-cock, a gauge-glass being fitted to indicate the height of the water in the separator.

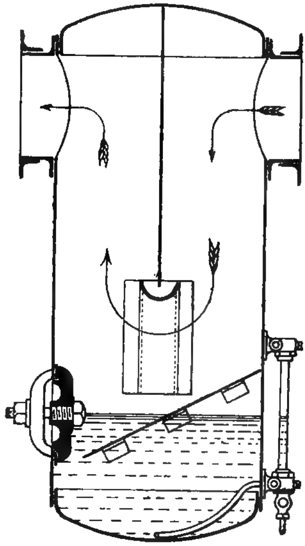


Fig. 261.

As any neglect in draining this vessel might lead to serious consequences, it is advisable to fit a reliable automatic trap. The Belleville boilers in particular adopt this automatic arrangement, as shown in Fig. 262, where the float, instead of acting direct on the drain-cock itself, works a small steam piston, which in its turn works the draining gear.

Frequently the fittings described in paragraph 194 as oil separators, and shown in Figs. 289 and 290, are used as steam-dryers, being placed close to the engines on the main steam-pipe.

Separators must not be confused with traps, or receivers for collecting condensed water, into which the discharges from neighbouring traps are led, when they are situated too far to discharge direct into the condenser. This class

of receiver is being fitted in connection with auxiliary machinery situated at a distance from the main engine-room, and may sometimes be of considerable dimensions. They should be fitted with gauge-glasses, but not with automatic discharge cocks.

Those separators which work on the principle of adding heat to the steam are known as steam-dryers or super-heaters according to the quantity of heat which it is intended to add; that is to say, according as it is desired to obtain dry saturated steam, or steam heated some degrees above the point of saturation. There is, after all, not much difference between the two, except for the amount of surface, and they usually form a kind of supplementary boiler placed at the base of the funnel.

The boilers designed by M. Dupuy de Lôme were fitted with superheaters on this principle (Fig. 263), but they were of little use.

Lafond superheaters were tried at about the same time and were composed of large bent tubes fitted into the base of the funnel (Fig. 264).

The apparatus was heavy, occupied a lot of space, and was of very little good, being taken out after it had been in service for a very short time.

Steam being a bad conductor, necessitated the use of large surfaces, which entailed heavy weights and the occupation of a large amount of space, and this has led to the complete abandonment of superheaters on board ship, in spite of the theoretical advantages of superheated steam.

If the study of superheating is taken up to-day, it will be under very different conditions to those obtaining in the early days. We are no longer content with a small rise of temperature to counteract the cooling action of the cylinders. This small rise did not show any saving, and could not, according to the mechanical theory of heat, be expected to do so.

AUTOMATIC DRAIN ON STEAM SEPARATOR.

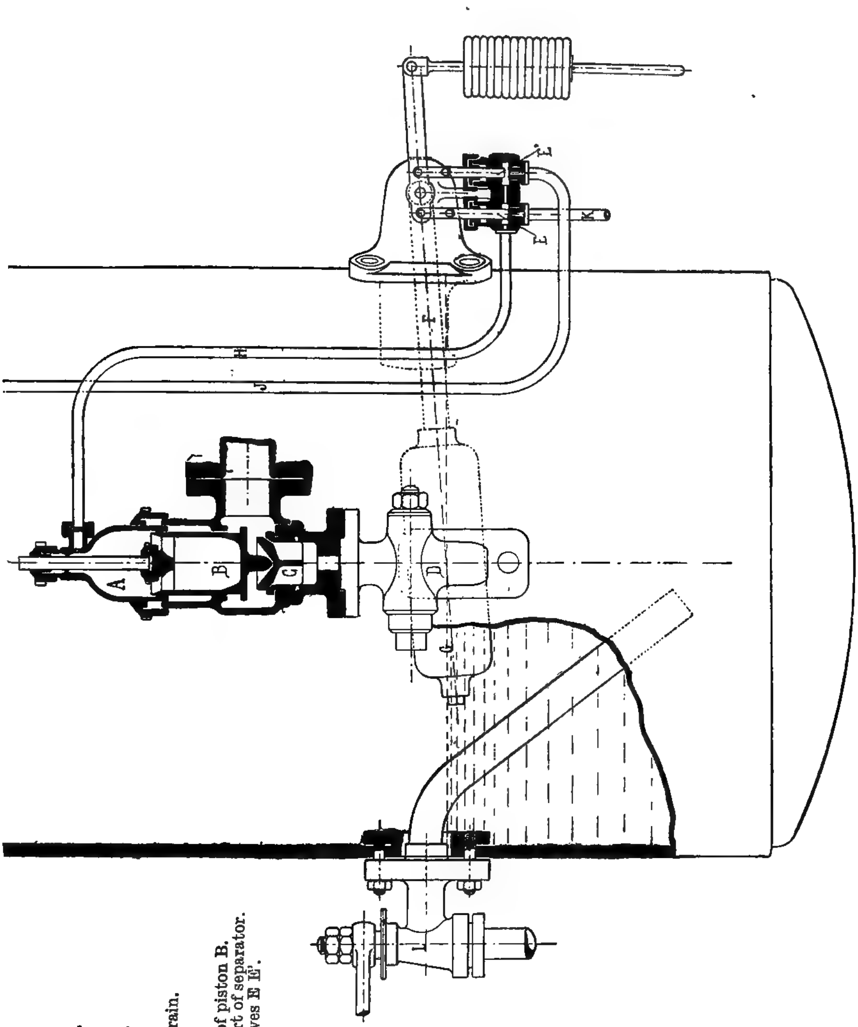


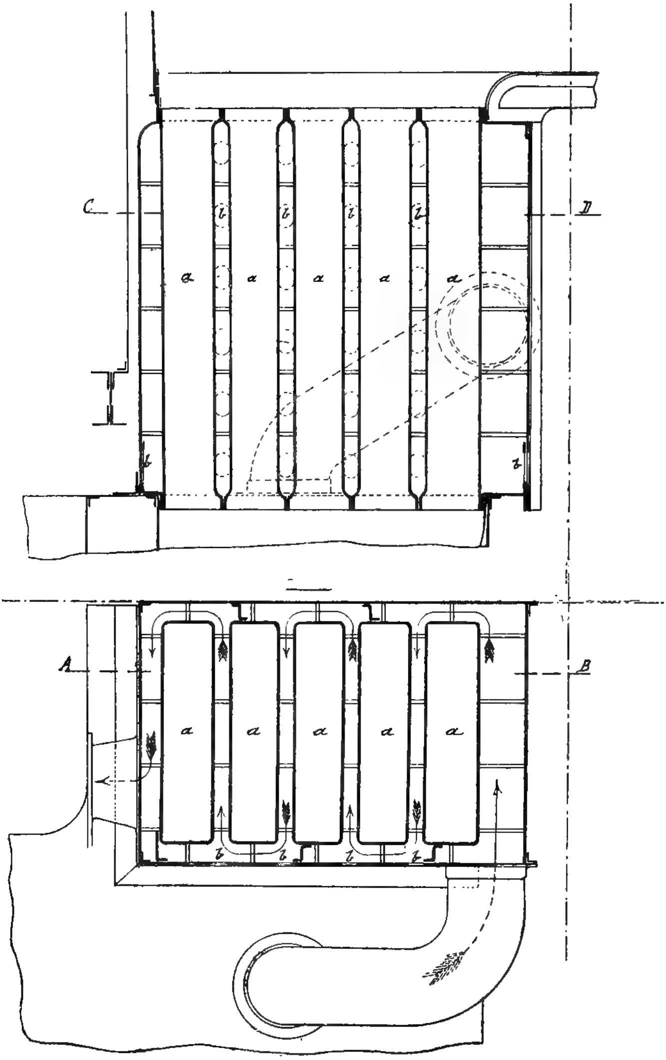
Fig. 262.

A. Automatic drain.
B. Piston of drain-valve.
C. Valve.
D. Inlet to drain-valve.
E E'. Valves controlling drain.
F. Valve lever.
G. Float.
H. Steam to upper side of piston B.
J. Steam from upper part of separator.
K. Drain from small valves E E'.
L. Hand drain.

PROVENCE.

SUPERHEATER.

Section on A B.



Section on C D.

Fig. 263.

A, Passages for the hot gases. B, Inspection or manhole doors,

JÉRÔME NAPOLÉON.

LAFOND SUPERHEATER.

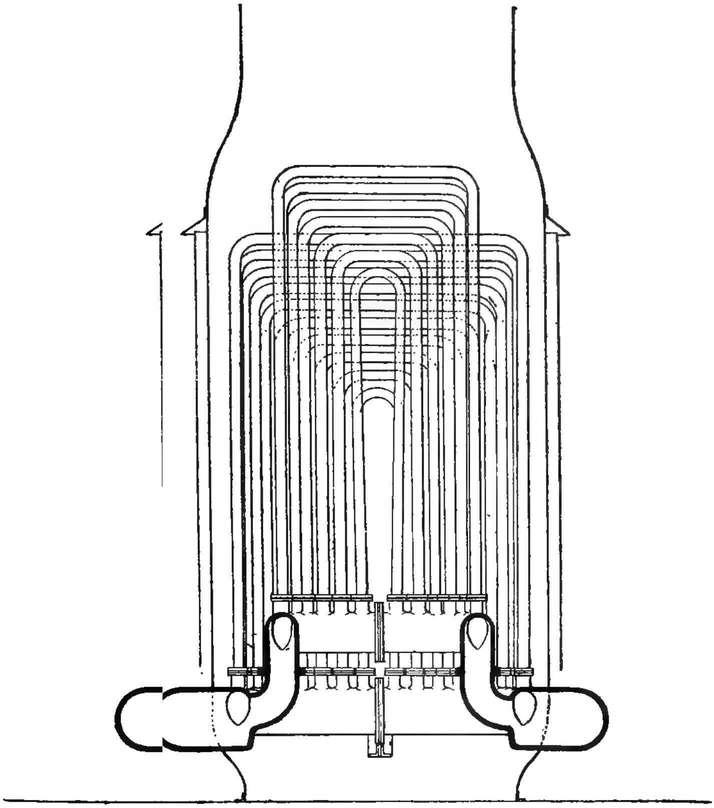


Fig. 264.

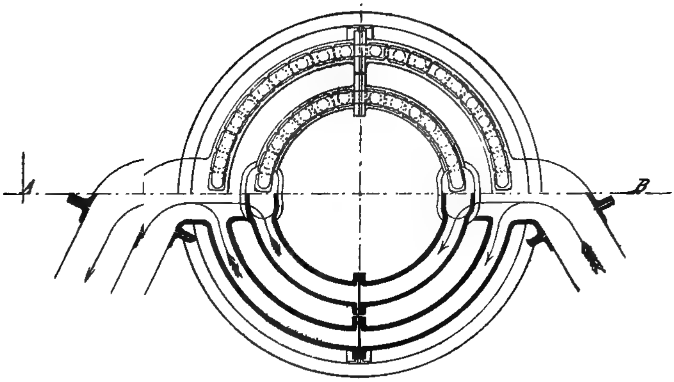


Fig. 264A.

The use of mineral oils has permitted a change to be made in this direction, but the possibility of being able to carry out a satisfactory installation on board, has not yet been proved.

On land one is less cramped for space and weight, and the trials with superheated steam have not had to be abandoned.

CHAPTER XVIII.

FEED ACCESSORIES.

186. *Water-gauges.—Gauge-cocks.*—The question of the quantity of water in all marine boilers is one of special interest, not only in tubulous boilers, but in those of cylindrical form, as the importance of keeping down weight on board ship has a tendency to reduce to a minimum the amount of water allowed, and thereby lowers the water-level in the boiler. In cylindrical boilers the normal water-level is usually about 8 ins. above the top of the combustion-chamber. The majority of serious accidents of which the cause could be determined, have been due to the lowering of the water-level. For instance, on the torpedo-boat No. 122, where the splitting of the crown of the furnace caused the death of a stoker, it was proved that the water-gauges were not registering correctly. On the *Wattignies*, in the same way, it was proved that when a Fox furnace collapsed the water was very low at the time.

The water-level is generally shown in a glass tube called a gauge-glass. It is essential that the water in these gauges be protected from the agitation caused by ebullition; that it be free from suspended matter, which might be deposited on the surface of the glass; and lastly, that the temperature be kept down, in order to avoid the glass breaking, owing to the cold currents of air in the stokehold. To ensure these conditions the gauge-glass is fixed, not to the boiler itself, but on a brass column called the gauge-column, standing quite clear of the boiler,

to which it is attached, and with which it communicates by two copper tubes of considerable length, the top one going to the steam-space, the lower one to the water-space. These two pipes are fitted with cocks or valves.* The gauge-

ORDINARY WATER GAUGE.
(French pattern.)

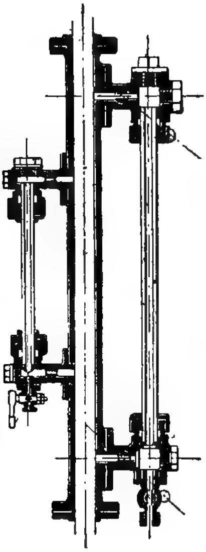


Fig. 266.

LOUPPE WATER GAUGE.

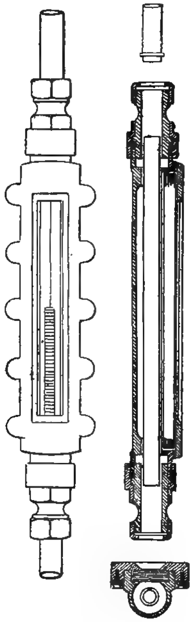


Fig. 267.

HOPKINSON'S AUTOMATIC WATER GAUGE.

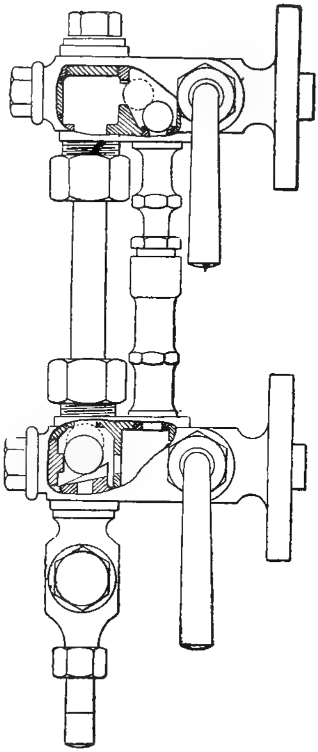


Fig. 268.

column sometimes has two gauge-glasses of different lengths (Fig. 266).

The glass tube fits into brass sockets communicating

* This differs materially from British practice where the connections to this boiler are as short and direct as possible, and no cocks or valves other than those used for blowing through the gauge are permitted.

through two cocks with the gauge-column. The handles of these cocks, which are connected by a rod, are so arranged that they cannot close automatically, and have to be raised to shut them. The upper end has a screw-plug for inserting the glass tube and a drain-cock is fitted at the bottom; two small stuffing-boxes, one at each end of the glass tube, complete the apparatus.

Care must be taken that the tubes and passages are all kept clean and clear, and engineers should be drilled to shut the cocks as sharply as possible when a glass breaks and so prevent the filling of the boiler-room with steam and the consequent panic which so often occurs, especially among inexperienced stokers.

There are two ways of preventing the dangers arising from a broken glass; one is to protect it by a cover, the other is to make the apparatus self-closing. An example of a protected glass is shown in Fig. 267, this being the Louppe system, in which the water-level is seen through a second glass cover. An example of a self-closing apparatus is given in Fig. 268—a design in which the passages are closed by balls driven on to their seats by the sudden rush of water. In the first system it is difficult to see the water, and in the second there is always the fear of the passages becoming blocked. Up to the present time no device has been designed which can be said to give complete satisfaction.

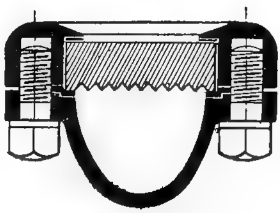


Fig. 269.

The gauge-glasses on large cylindrical boilers have by force of circumstances to be placed high up, and cannot always be easily seen from the stokehold floor. To render the water-level more easily visible, gauges of the Klinger type invented by M. Lavezzari, of Paris, have been used. This ingenious type of gauge-glass consists of a flat sheet of glass, striated on the inside,

backed by a curved metal casing (Fig. 269). The water appears dark while the steam-space is quite light.

The water-level in the gauge-glass is not the same as that of the boilers: there are several reasons for this difference.

In the first place, the water in the gauge-column and its connections is colder, and consequently more dense, than that in the boiler. For a difference of 180° Fahr. the density of the water in the gauge-glass is 1.045 times that in the boiler; this in $6\frac{1}{2}$ ft. may therefore make a difference of $3\frac{1}{2}$ ins. in the level, that in the gauge being the lower. Although the difference of temperature would probably not amount to 180° Fahr., nevertheless it is not advisable to make the height of the column of water more than $6\frac{1}{2}$ ft.

In the second place, if the density of the water in the boiler is high owing to condensation, the gauges are continually being replenished with pure or fresh water, and there is a tendency to a condition of things the inverse of the preceding one. For instance, if, while the water in the boiler marked 2° on the salinometer, and the water in the gauge-column were quite pure, the ratio of the specific gravities would be 1.000 to 1.052; consequently, for a column $6\frac{1}{2}$ ft. high the level shown in the gauge-glass would be 4 ins. too high. Tubulous boilers are almost free from this defect owing to the purity of the water it is necessary to use in them.

These two causes of error, of opposite effects, in the indication of the water-level are the only ones to which tubular boilers are exposed. The amount of error can always be determined by using the gauge-cocks. In tubulous boilers, where there is a rapid circulation, a much more serious cause of error arises, due to the differences of pressure existing in the boiler balancing the inertia of the columns of water in motion. It is this

action in the Belleville boiler by which, as the proportion of steam increases and the upward velocity is accelerated, the pressure in the lower drums is increased, and is indicated by a rise of water in the gauge-glass of 4 ins. or even of 8 ins. above that in the boiler. In the D'Allest boilers there is, in addition, a deformation of the surface of the water which causes the indications of even the gauge-cocks to be inaccurate (see Fig. 154).

It should be noted that if the openings are not kept clear, throttling of the steam passage may produce a marked depression owing to the condensation in the interior of the tube. M. Zieger made some convincing experiments at Cherbourg on gauge-glasses in which the section of the steam opening could be varied from 3.89 ins. to .03 sq. in.; the depression varying 0 to $5\frac{1}{2}$ ins. In boilers with accelerated circulation the gauge-glasses may be placed direct on the upper drum without the intervention of a gauge-column.

The gauge-cocks, principally intended as checks on the water-gauges, are three in number, and are fixed to the front of the boiler; one is at the normal water-level, the second 4 ins. below, and the third 4 ins. above this level. They are easily kept in order, and never deceive an experienced hand: to the novice they appear to invariably eject nothing but steam.

The lower gauge-cock can also be used for drawing off water for testing the density of the water in the boiler.

Small needle valves are sometimes fitted as gauge-cocks.

Fusible plugs have been fitted to indicate when plates become overheated, but they are not in general use in the French Navy. The fusion of a plug is a very serious matter, as the damage cannot be made good without drawing the fires; and where one boiler only is employed, the safety of the vessel itself might, under certain circum-

stances, be jeopardised by the action of this "safety" device.

It has been shown (paragraph 118) that fusible plugs were used for a time on the D'Allest boilers; none, however, were fitted on the boilers of the *Jauréguiberry*, where the overheating, which caused the bursting of a tube, would probably not have fused the plugs.

The warning or alarm whistle, actuated by a float, has never been applied to marine boilers.

187.—*Feed-water Inlet.—Hand Check-valves.*—The method of introducing the feed water into the boiler is an important matter. By forcing the water into the steam, in the form of a fine spray, the air is got rid of, and salts insoluble at high temperatures, such as sulphate of lime, are immediately precipitated; on the other hand, by introducing it in a body into the water, useful currents may be set up, or existing currents be assisted. For cylindrical boilers, the first method is adopted in the French Navy; the second, in the American Navy. Amongst tubulous boilers, the first method obtains in the Belleville; the second, in the Normand boilers. It is imperative that the feed-water be delivered in the main drum, in those tubulous boilers where there is a main drum common to several furnaces, in order to simplify, as far as possible, the feed pipe and the regulating of the feed check-valves.

On the front of the boiler, close to the feed-water inlet, is placed the apparatus for regulating the level of the water.

The level of the water is always regulated by simply altering the section of the inlet. In the case of pumps driven direct from the main engines, should too much water be delivered, the excess is returned by means of a loaded bye-pass valve to the hot well or feed-tank. In the case of the Weir and similar types of pump the increase in

resistance due to closing the check-valves, serves to slow up the pump.

The feed supply is generally regulated by a so-called feed check-valve, which is raised by the water on entering, but does not allow it to return. The section of the inlet is increased or diminished by raising or lowering a hand-screw, to regulate the lift of the valve. The type adopted in the French Navy as a hand feed-check is the one known as the "Indret" model. In this, the valve is placed in the plug of a cock or tap, as shown in Fig. 270. By closing the cock the valve is cut off from the boiler, and can therefore be detached for inspection and cleaning.

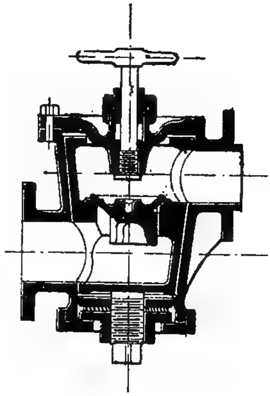


Fig. 270.

A certain amount of regulation by hand is always necessary when several boilers are fed by one pump or from one common feed-pipe. In fact, if there exist slight differences of pressure in several of the boilers—as often occurs—the valves will open widest at the boilers where the pressure is least, and will remain closed at the others; but it may so happen that while the water is low in all the boilers water may be most urgently needed in one of the boilers where the pressure is greatest.

188. *Automatic Feed-water Regulators.*—The adjustment of the feed is very much facilitated where the regulating valve is actuated by a float. This arrangement is more particularly of use on tubulous boilers, where the slightest delay in the admission of the feed may cause a dangerous drop in the level of the water in the boiler. It is also to be recommended on large vessels, where attention has to be divided amongst a large number of tubulous boilers.

Automatic regulators were introduced into the French Navy by M. Belleville. Fig. 271 shows the design now in use on his boilers, which has varied but little since its first introduction. The valve is controlled by a lever acted on by two opposite forces, the one a spring tending to shut it, the other a float which opens it as the water-level falls. A special rod works the lever to allow of opening by hand, independently of the float. The vessel in which the float works is placed on the column leading the water from the separator to the feed-collector.

BELLEVILLE AUTOMATIC FEED-REGULATOR.

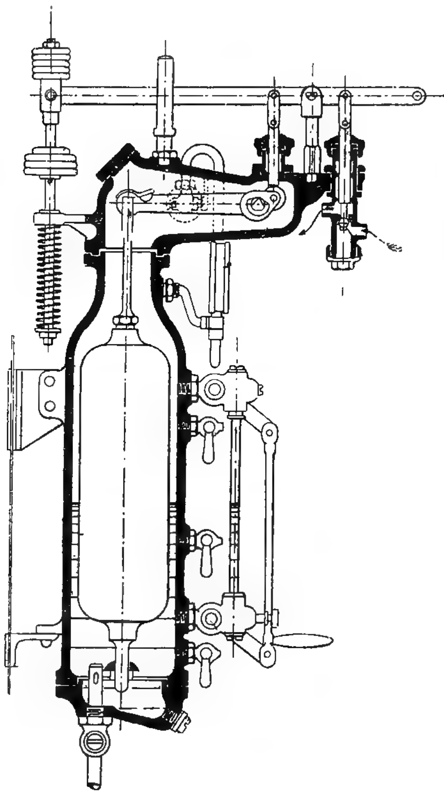


Fig. 271.

The pressure in the feed-pipes of the Belleville boilers is about 120 to 150 lbs. above that in the boilers themselves.

A great number of various designs of automatic feed regulators have been brought out owing to the development of tubulous boilers.

Figs. 272, 272A, 272B, and 273, show examples of two designs, one with a plug, the other with a slide valve. They are not novel in principle, and were designed by M. Sigaudy for the boilers of the *Jeanne d'Arc.*

In Fig. 272, which has a plug, the hand regulator is worked by altering the opening by means of a sleeve

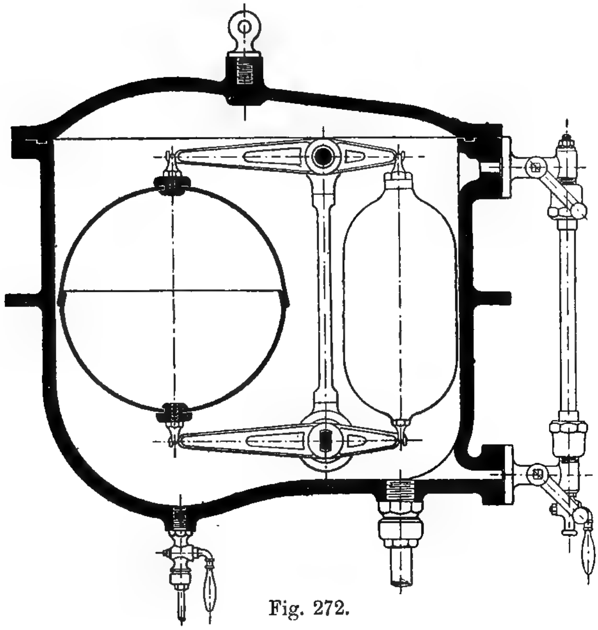


Fig. 272.

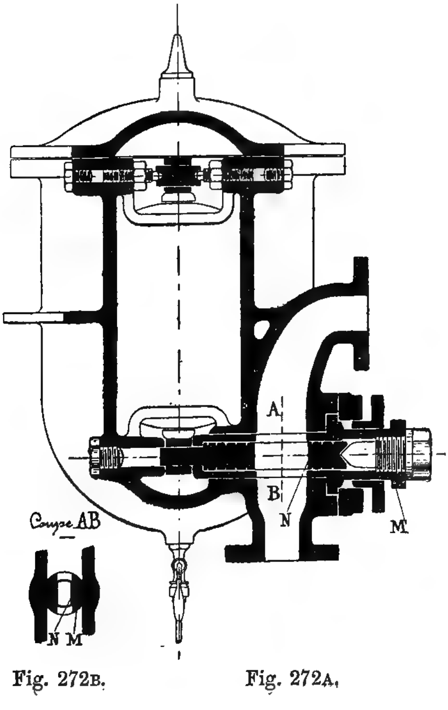


Fig. 272B. Fig. 272A.

working on the outside of the plug actuated by the float (Fig. 272A).

In the design with a slide valve (Fig. 273), all that is needed is to alter the length of the slide rod. This type was fitted on the *Château-Rénault*, only a double-seated valve was used instead of a slide valve. The general arrangement can be seen in Fig. 273, from which it will be gathered

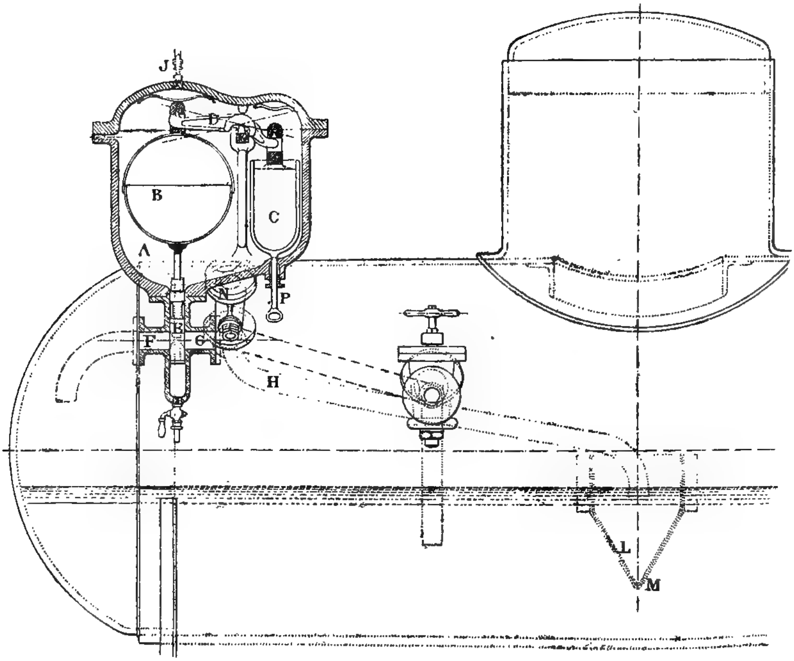


Fig. 273.

that the apparatus can be placed at any height. The bottom part of the vessel is connected with the upper drum of the boiler at or about its normal water-level, while the top of the vessel is connected by a small pipe to the condenser.

The Thornycroft regulator is placed inside the boiler. It is composed of a float, partly balanced by a counterpoise, which actuates a double-seated valve by means of a lever

and link. Regulation by hand is accomplished in a simple manner by adjusting the vertical position of the pivot about

THORNYCROFT AUTOMATIC FEED-REGULATOR.

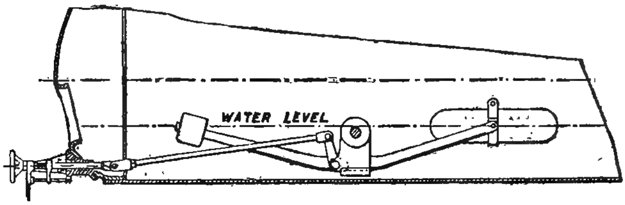


Fig. 274.

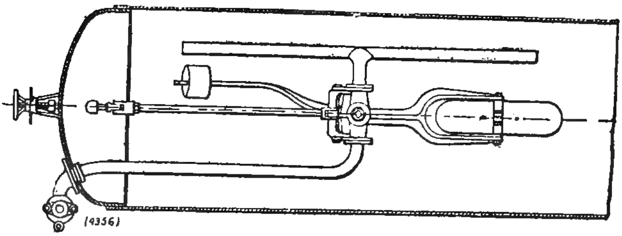


Fig. 274A.

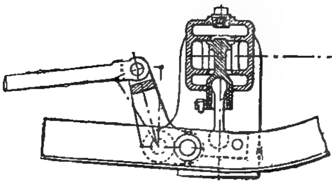


Fig. 275.

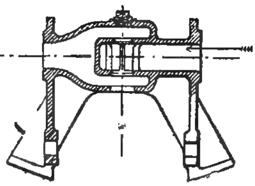


Fig. 275A.

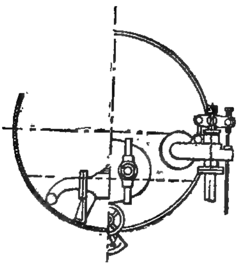


Fig. 275B.

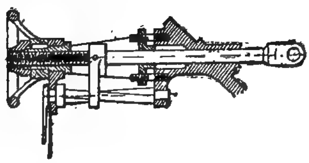


Fig. 275C.

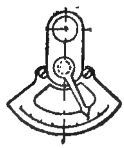


Fig. 275D.

which the float lever turns. As the parts moved by the float do not pass through stuffing boxes, the variable

friction due to this cause is eliminated, and the gear is consequently very reliable.

M. Messier has contrived a highly original arrangement (Fig. 277) in which the regulator is actuated by a diaphragm; the upper surface of this diaphragm is under a constant pressure, while the pressure on the under side of it is increased by the weight of the column of water H, directly the level of the water in the boiler gets below the opening of the long tube which terminates at the normal level.

M. Normand has recently fitted to some of the French torpedo-boats in which there are only two boilers, a very simple arrangement to reduce the care and attention necessary in supervising the feed. He connects the upper steam drums with one another, below the water-level, by means of a pipe of large diameter and also the two bottom water drums in a similar manner. This enables a free circulation of water to take place between the two boilers, which are separated by the stokehold floor, only one feed supply for two boilers being necessary, and it eliminates any differences there may be in the rate of working of the boilers. Thus the total water passing through the engine is returned to the boilers, without any supervision as to the quantity going to each boiler being necessary.

Mr Yarrow some time ago introduced a feed regulating apparatus of somewhat original design. He connected the steam pipe of the feed donkey pump direct to the top drum of his boiler in such a way that its inlet was just above the normal water-level, and could be varied at will (Fig. 276). If the water was below the inlet, steam passed to the steam cylinder of the donkey pump in the usual way, and water was forced into the boiler at a high velocity. This raised the water-level and caused the orifice of the internal steam-pipe to take water instead of steam, thereby slowing down the engine. It continued to work slowly, extracting the surplus water from the boiler, due to the difference between

the capacities of the steam and water cylinders, until the water in the boiler was brought down to the normal water-level. This system not only raised the water-level if too low, but automatically reduced it if too high. The exhaust from the steam cylinder was led to the condenser and went to heat up the feed-water when steam was passing through the cylinder; should the cylinder be working hydraulically the hot water was simply taken from the boiler through the steam cylinder and passed to the condenser. This system, though involving a slight loss of heat, had the advantage of mechanical simplicity, but it was open to many obvious objections, and its use has since been discontinued.

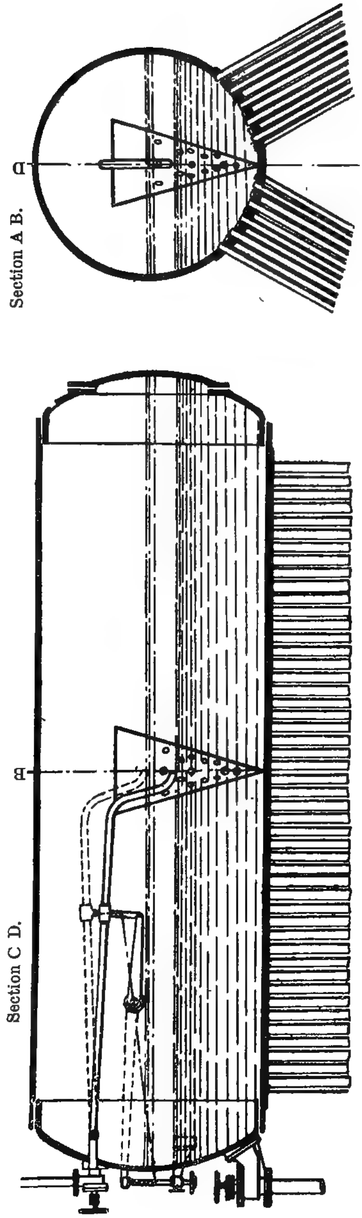


Fig. 276A.

Fig. 276.

YARROW AUTOMATIC FEED AS APPLIED TO THE YARROW WATER-TUBE BOILER.

Messrs Weir, Mumford, Babcock & Wilcox and Niclausse, amongst others, have introduced feed-regulators actuated

by floats, descriptions of which are given in the editor's book on water-tube boilers.*

MESSIER'S AUTOMATIC FEED-REGULATOR.

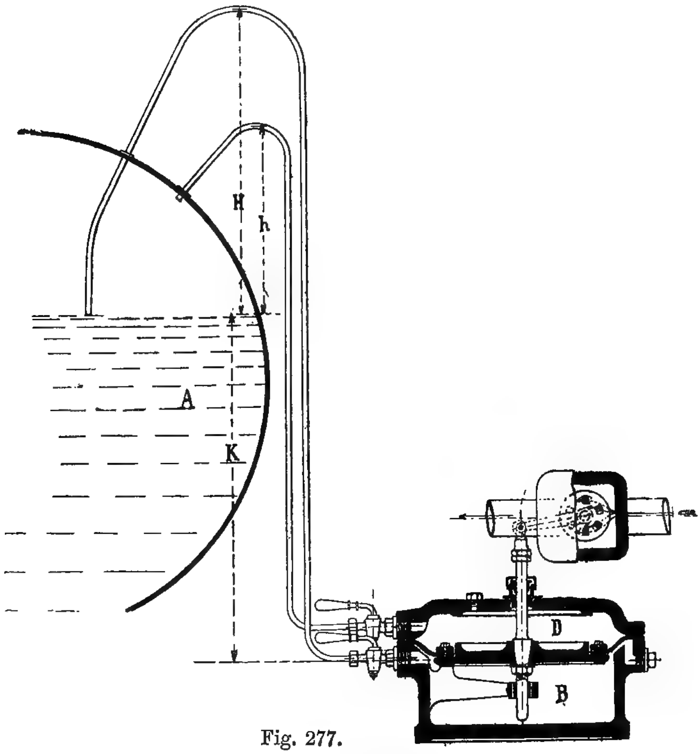


Fig. 277.

A. Boiler at working pressure P.
B. Receiver at pressures $\begin{cases} P+K, \\ P+K+H. \end{cases}$
D. Receiver at constant pressure $P+K+h$.

189. *Saturation and Salinometers.—Continuous Blow-off.* When a boiler is fed with water containing salts, these latter are concentrated by distillation. The water in the boiler soon becomes very highly saturated, which necessitates the blowing off of a quantity of this highly saturated

* "Water-tube Boilers," by Leslie S. Robertson. John Murray, 1901.

water, containing an amount of salt equal to that brought in by the feed-water.

The density is determined by taking the specific gravity of the water at 203° Fahr. with a little hydrometer called a salinometer. This instrument is so graduated that it indicates 0° in fresh water, 1° in sea water, and then as many degrees as the water contains multiples of the quantity of salt in sea water.

When boilers were fed with sea water the saturation was kept at 3° by a constant blow-off through a pipe fitted with a cock; the opening of this cock was regulated according to the amount of saturation recorded from time to time. The resultant loss of heat by this constant blowing-off came to about 12 per cent. of the total amount given to the boilers, when the saturation was kept down to 3°; the loss would still have been 9·5 per cent. had the saturation been 4°

When boilers were fed with fresh water and losses were made good with sea water a saturation of 4° was allowed.

190. *Scum, Blow-off, and Blow-down Cocks.*—As at the present time both feed and "make up" with sea water are prohibited, the extraction of the sea salt from the boiler has lost most of its importance. On the other hand, great attention is being paid, and justly so, to the removal of all mineral oil which may have been brought in by the steam, and which at first floats on the surface of the water. Water instead of being blown off from the bottom of the boiler, as formerly, is now blown off from the surface.

Scum or surface blow-off must take place exactly from the surface, and this is arranged by attaching the end of the blow-off pipe to a float. Fig. 278 shows an apparatus constructed on this principle, and tried on the *Hâleur* at Brest. The blow-off from the surface should be all but

continuous, for, as has been pointed out in paragraph 49, the oil does not float long and is soon precipitated.

The use of floating apparatus is only applicable to cylindrical boilers. For tubulous boilers several kinds of "boiler cleaners" have been invented in England and in America; but the only way to obviate the presence of oil in the boilers is to purify the feed-water, as will be described further on.

HÂLEUR
SURFACE BLOW-OFF.

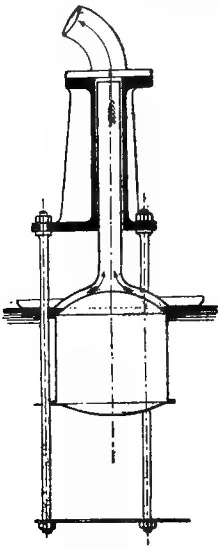


Fig. 278.

As there is always a liability of sea water finding its way into marine boilers, due to leaks in condensers, distillers, etc., a blow-off is always fixed to the bottom of the boilers. Where boilers are fitted with settling drums the blow-off cock is naturally fitted to these.

All boilers have at their lowest point a cock through which they can be completely emptied. For the sake of cleanliness the water from the boiler should not be drained into the bilges, but, as far as possible, into the sea. Any small quantity of water that may be left is drained into a tank and pumped out.

191. *Apparatus for Artificially Circulating the Water in the Boiler.*—It has already been pointed out that the shells of boilers may be subjected to considerable fatigue during the operation of getting up steam, due to the differences of temperature arising from the stagnation of the water at the bottom of the boiler. The absence of any motion in the water is all the more unfavourable to the diffusion of heat since this takes place by convection and not by conduction. Consequently many devices have been thought of to impart motion to the water.

The first devices tried were the "Hydrokineters," a kind of Friedman injector in which jets of steam, driven along a conical nozzle, draw in the surrounding water; the artificial current thus set up is so directed as to carry the cold water from the bottom up into the more heated parts. That these hydrokineters are efficient there is no doubt, but their action is very slow. On board a liner, where steam was raised in the careful and cautious manner usual on large merchant

WEIR'S HYDROKINETER.

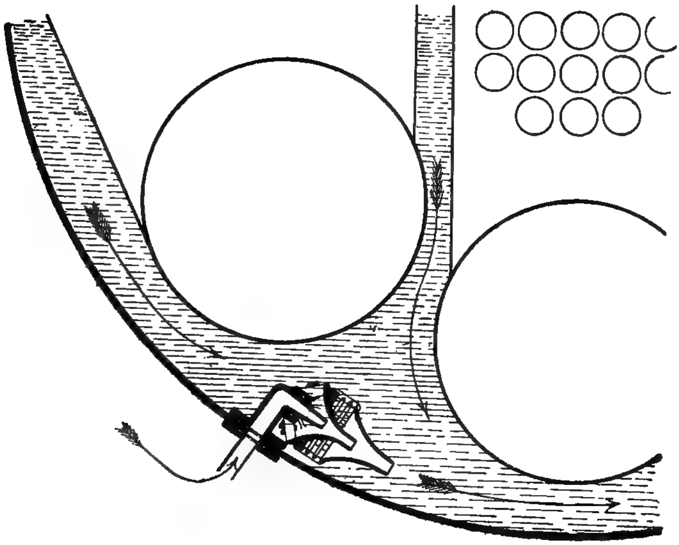


Fig. 279.

vessels, it was found that, four hours after lighting up, the temperature of the water at the surface was 205°, while at the bottom it was only 73°. After a hydrokineter had been fixed, under the same conditions, and in the same length of time, the temperatures were respectively 205° and 144°; it took six hours more before the temperature was equalised throughout. Hydrokineters, it will be seen, do not answer to the exigencies of vessels of war, where the time taken to raise steam is of great importance. The

hydrokineter has two other drawbacks ; it necessitates an auxiliary boiler under pressure and it ceases to act when the temperature and pressure of steam in the main boiler has reached that of the auxiliary boiler.

In the American Navy the steam jet has been replaced by a jet of feed-water forced through a conical nozzle. The arrangement answers well as long as the boiler is at work, but when at rest and raising steam the injector is of no use, that is to say, it is inoperative just at the time it is most needed.

ARRANGEMENT USED FOR CIRCULATING THE WATER IN THE BOILER BY MEANS OF THE FEED-WATER.

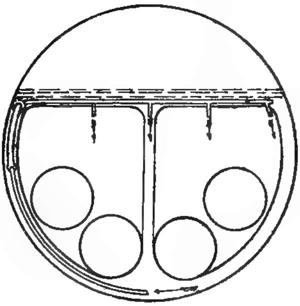


Fig. 280.

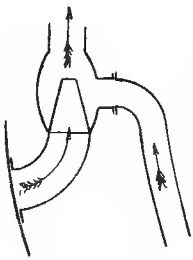


Fig. 281.

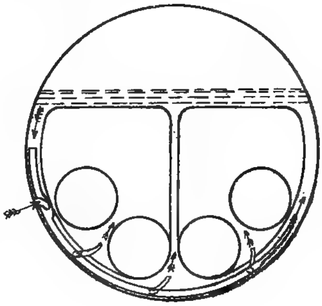


Fig. 280A.

The circulators used at Indret by M. Garnier are thoroughly efficient. They consist of small centrifugal pumps, fixed outside the boilers, which take water from the bottom and discharge it a little below the water-level. The pumps are turned by hand while raising the pressure, and are worked by steam when sufficient pressure has been raised. A small $1\frac{1}{2}$ I.H.P. engine is sufficient to produce vigorous circulation in a boiler with two or three furnaces. The efficiency of these circulators has been well established, both as regards the absence of fatigue to the shell during lighting up and the production of steam while under way. It has also been noticed that they tend to minimise

over-heating of furnace crowns and leakage at the tube-plates. This apparatus is now in general use on cylindrical boilers in the French Navy.

Centrifugal pumps such as described above were fitted many years ago to the locomotive type boilers of H.M.S.

ISLY.

Centrifugal Pump for Circulating Water in Boiler.

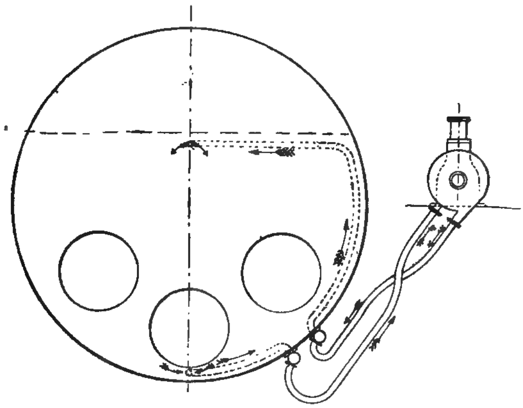


Fig. 282.

Polyphemus with a view of preventing the leakage of the tubes which took place when the boilers were forced. They failed however, to effect the desired object, and were removed together with the boilers; the low cylindrical or gunboat type boiler being substituted without the centrifugal pumps.

192. *Water Purifiers.*—Both the water in boilers and the feed-water contain marine salts, fatty acids resulting from the decomposition of tallow (where this is used in the stuffing-boxes), mineral oil, and air, all of which are harmful, as has been shown.

The marine salts are removable through the blow-off at the bottom of the boiler, as described above; the salts of lime are immediately precipitated on their arrival in the boiler,

when the feed-water is fed into the steam-space. It only remains to describe the apparatus designed to extract or neutralise the other substances contained in the feed-water. Steam feed-water heaters (described in paragraph 196), which in the first instance were fitted solely with a view to economy, were found to possess certain properties very useful in the purification of water. But the heating surfaces of surface heaters rapidly become coated with grease and require to be frequently cleaned; whatever is got rid of in this way is so much gain to the boiler. Further, any air taken up by the water after leaving the condenser is set free in the heaters, where it is discharged through cocks provided for that purpose.

The problem of extracting the fatty acids has never been satisfactorily solved. When, some twenty years ago, it was first attempted to get rid of these acids by the help of lime, a special apparatus was designed by M. Risbec for automatically injecting into the boiler a fixed proportion of lime. This has been officially adopted in the French Navy. At first the apparatus consisted of two force pumps, and was rather complicated. In Fig. 283 is shown a much simpler apparatus which was designed in 1880 by M. Dudebout. The mixing of the lime and water is effected at the bottom of a chamber placed about half-way up the apparatus. The water, coming from a reservoir in which a constant level is maintained, is admitted through cocks worked by hand. The powdered lime is introduced through the tube *e*. The stirring is effected in the lower chamber by causing the water to circulate round the baffles shown in the figure. The mixture then passes into a reservoir, from which it is blown direct into the condenser. In this last reservoir a constant level is automatically maintained in order to prevent air entering the condenser. The figure shows a form of the apparatus suitable for two condensers.

Lime water is always used for filling up tubulous

boilers when laid by, and is also often employed in

DUDEBOUT'S FEED-WATER PURIFIER.

Section on E F G H.

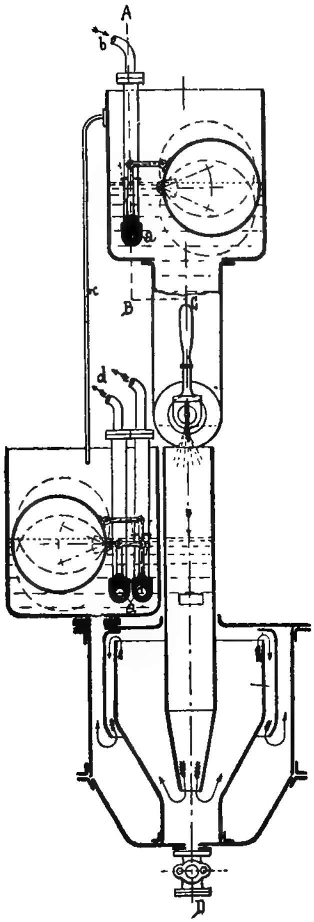


Fig. 283.

Section A B C D.

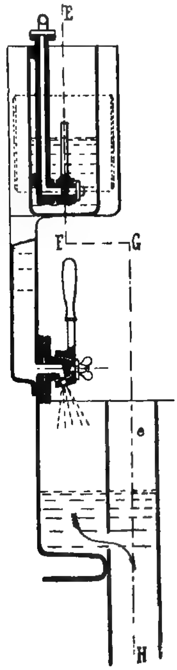


Fig. 283A.

DETAILS OF COCK *a*.

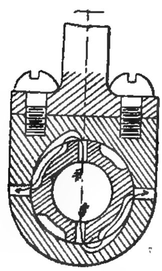


Fig. 284.

a. Water inlet controlled by float.
b. Pipe from feed discharge.
c. Overflow pipe.
d. Suction pipe to condenser.
e. Pipe for introduction of powdered lime.

ordinary working when a simple mixing vessel is used

connected with the hot well. The use of alkaline carbonates has been entirely abandoned, as mentioned in paragraph 82. With the exception of lime, which, when used under steam is not without its drawbacks, all addition is avoided, and rightly too, of any new chemical substances to those already too numerous, contained in the feed-water.

193. *Zinc Plates.* — The principal chemical, or rather electro-chemical agent, actually employed as a preventative of corrosion consists of zinc plates suspended inside the boilers as near to the feed-water inlet as possible, except when this is in the steam-space.

The effect of the zinc is to neutralise the free acids in the water by combining with them; it takes the place of iron in causing the precipitation of salts of copper when present, and finally, and above all, it produces a galvanic effect, keeping the iron in an electro-negative state, thus rendering it but little liable to oxidisation.

In order to bring about the desired galvanic action, a simple voltaic cell is formed; the zinc plates are attached to the iron to be protected, by strips of copper (Fig. 285), care being taken that contact is established between perfectly clean surfaces. All direct contact between zinc and iron must be carefully avoided;* it is even advisable to provide means for catching such pieces of the attacked metal as may become detached. The recognised proportion between the surfaces of zinc and iron is 0.015 to 1.000, which means placing as much as 180 to 220 lbs. of zinc per furnace in cylindrical boilers.

Fig. 285.

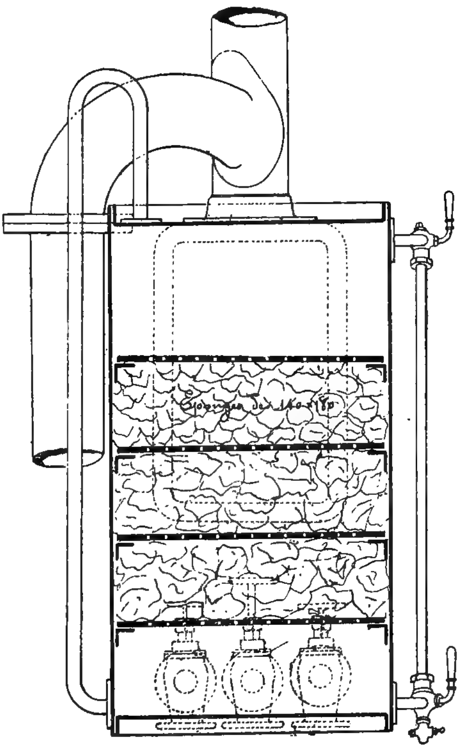
Zinc plates are sometimes placed in the hot wells, feed-tanks, etc., not so much to preserve their surfaces as to commence the process of the neutralisation of the water.

* In British practice the zinc slabs are attached to the boiler by iron hangers.

These zinc plates have been called by Hannay and others "electrogenes." Zinc has been credited with the property of rendering boiler deposits less hard and adherent. It has already been pointed out in Section 83 that the preservative action of zinc on iron has been questioned.

194. *The Extraction of Mineral Oils from Feed-Water.—Sponge Filters.—Cloth Filters.*—To solve the difficult problem of getting rid of the mineral oil before the feed-water reaches the boiler, it is necessary to have resource to mechanical means, for no known chemical agent is capable of absorbing and precipitating the oil.

NORMAND SPONGE FILTER.



Feed-pump suctions.

Fig. 286.

An apparatus applicable to engines of all sizes is the sponge filter (Fig. 286). The feed-water is made to pass through it after leaving the air-pump, the feed-pump suctions being placed at the bottom of the filter. The sponges arrest the mineral oil fairly well, while allowing the water to pass; they last for a considerable time but have to be periodically cleaned with soft soap or caustic potash.

The filter is provided with a by-pass, enabling the feed to go on while cleaning is being done.

The sponge filter was used for the first time in France by M. Normand on his torpedo-boats.

The great cost of sponges has caused them to be replaced as filtering material in the large American boats by bundles of hay.

In practice the introduction of a filtering apparatus entails a slight modification in the working of the air-pumps. It is therefore advisable, at least on big engines, to place the filter on the discharge side of the air-pump, so as to allow the water to get to the feed-pumps freely. Sponge filters, though they have rendered good service in the past, are open to various objections. They are heavy and take up a lot of room, and, moreover, their efficiency is not maintained over any length of time. When clean they allow about 20 per cent. of the oleaginous matter held in suspension to pass through, and when dirty they allow a large quantity of grease to pass; and, further, they do not give any indication when they cease to work efficiently. They also retain a certain quantity of air which is given up to the feed-water, and is pumped into the boilers, giving rise in some instances to active corrosion.

Arrangement for Changing Sponges without Stopping the Feed.

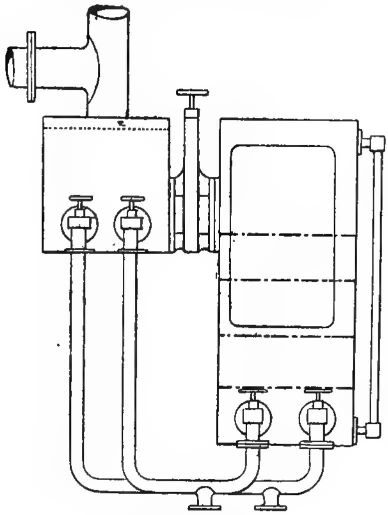


Fig. 287.

Filters in which cloth or similar material stretched over frames is used give much better results. The

grease deposited on the cloth offers an increasing resistance to the passage of the water, but the actual result is not a diminution in the grease-extracting efficiency of the filter, but a decrease in the amount of water passed which is attended by a rise in pressure. This type of filter has the drawback of necessitating the addition of a small special pump to force the water through the filter as this load cannot be put on the air-pump. They are more costly than the previous type, and the cleaning

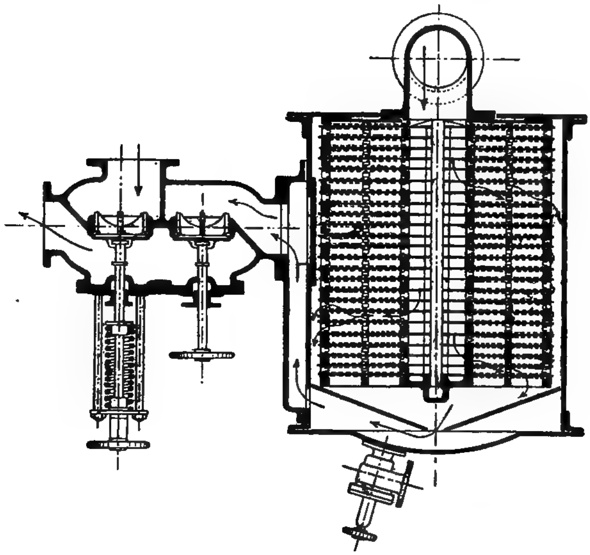


Fig. 288.

of the cloths is an expensive item. In spite of these drawbacks their undoubted superiority over the sponge filters is leading to their extended use.

There are a large number of cloth filters which work under pressure, but the Harris filter is the only one of this class which has been tried in the French Navy. The filtering surface of the Harris filter is very large, and is obtained by means of a series of cloths stretched on frames

through which the water passes. The water to be filtered enters at the centre and passes out at the sides, as shown in Fig. 288. The filter is arranged so as to be easily accessible for cleaning purposes, and a small valve on the feed-pipe which works an electric bell indicates when the pressure rises above a given amount, and the filter requires cleaning.

Comparative trials made on the *Bouvet* between the Harris filter and sponge filters conclusively proved the superiority of the former. The water contained a proportion of about ·0005 of grease, and the analysis of the water on leaving the filter gave the following results:

	SPONGE FILTER.	HARRIS FILTER.
After four hours . .	0.00012	0.00008
After eight hours . .	0.00016	0.00011
After twelve hours . .	0.00022	0.00012

On continuing the test the proportion of grease in the water after leaving the sponge filter was .0004, while the amount of grease arrested by the Harris filter was such that it had to be cleaned.

The Harris filter employed in the experiment could deal with five hundred times its own volume of water before it needed cleaning, that is 500 lbs. per square inch of filtering medium.

The measures taken at the present day to reduce the amount of air passing into the feed-water leads to the hope that this type of filter will be able to pass 700 lbs. of water per square inch of filtering surface. Should occasion require the Harris filter can be cleaned by blowing steam through in a reverse direction to that taken by the water, but this is only a temporary method, and the results are not entirely satisfactory.

In the Boothman filter the filtering cylinders are a framework covered with a single piece of cloth. The dismantling and cleaning of this filter should be rapid,

but to obtain sufficient surface the filtering cylinders must be numerous.

In the Rankine filter the perforated cylinders or cartridges carrying the filter cloth are enclosed in a cylindrical casing divided into three distinct sections, water passing successively through each.

Even the best filters, whatever their filtering medium may be, are only able to extract oil in suspension, and do

De Rycke's Oil Extractors.

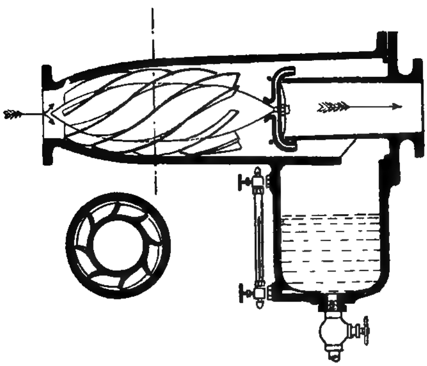


Fig. 289.

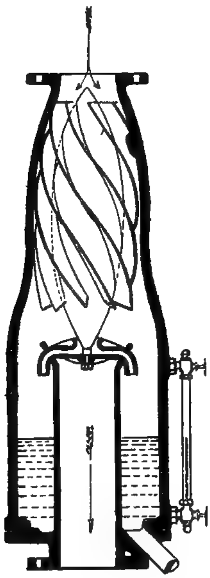


Fig. 290.

not arrest the more finely divided particles which form an emulsion with the water.

Mr Harris, in conjunction with Mr Anderson, has brought out an apparatus especially designed to purify the feed-water by the addition of chemicals and subsequent filtration. Various forms of apparatus for getting rid of grease and oil have been patented under the name of "grease extractors" or "oil eliminators"; the only ones

of real interest, because they are rational in principle, are those which act on the steam itself in its passage from the cylinder to the condenser.

The action of steam purifiers is analogous to that of other purifiers in that a curvilinear motion is imparted to the current, and the liquid particles impinging on the guide blades are arrested. The shape given to the guide-blades is much more complex than in other purifiers. The two Figs. 289 and 290 represent two patterns, the one vertical the other horizontal, and are sufficiently clear without any further explanation.

These types of apparatus may be very suitable to certain small vessels, but on the low-pressure exhaust of a large engine they would have to be of an excessive size.

195. *Condensers and their Effect on the Purity of Feed-water.* — One element which has an extremely important bearing on the life of the thin tubes of a water-tube boiler is the tightness of the condensers, but this is a subject which can be more properly dealt with when considering the details of engines than of boilers. Should salt water find its way into the feed-water either through leaky condenser tubes or glands, it may have serious effects on the life of the boiler. This has led to increasing the number of condensers so that one can be overhauled without throwing the others out of service. The feed-water on its passage through the air-pump may become intimately mixed with oil and air, and this has led to taking the feed-pump suctions direct from the bottom of the condenser, thereby allowing the feed-pumps to deal with the water and the air.pumps with the air.

196. *Feed-water Heaters Heated by Steam.—Calculation of their Theoretical Efficiency. — Surface and Injection Feed heaters.* — Steam feed-water heaters are in reality small

condensers, in that steam, that has already done work in one or two cylinders, is employed to heat the feed-water instead of sending it into the last cylinder, where only a portion of its heat would be turned into work.

Heaters, like condensers, may work either on the surface or by mixing, as in the jet condenser. The Normand pattern, shown in Figs. 291, 291A, is a surface-heater. The patterns used in England and in America are either surface-heaters, as in Fig. 292, or injection-heaters, as in Fig. 293.

The surface-heaters are the favourites in France. The reasons for this preference have already been given. Experience has clearly established the utility of steam-heaters, from the point of view of economy. The saving of coal consequent on their adoption has never been less than 10 per cent. when the position of the apparatus was well chosen. The primary cause of this saving, as far as can be shown by calculation, may be thus stated:—

Take the extreme case, from a purely theoretical point of view, of an engine working at a pressure of 284 lbs., and with quadruple expansion, under the following conditions:—

	Pressure. (absolute).	Temperature.	Total heat in thermal units of one pound of steam from 32° Fahr.
	Lbs. per Sq. In.	Degrees Fahr.	
Boiler	284	412	1208
First receiver . . .	115	337·9	1185
Second receiver . .	37	262·3	1162
Third receiver	8·5	185·7	1139
Condenser	1·4	114·2	1116

Assuming the temperature of the feed-water before it is heated to be 68°, this would require an application of 1,172 B.T.U. to convert it into steam at a pressure of 284 lbs. per square inch.

With the aid of the exhaust steam we can first heat the water to 114.2° without spoiling the vacuum; in raising a pound of water from 68° to 114.2°

$$\frac{46.2}{1116-46.2}=0.043 \text{ lb. of steam}$$

will be condensed.

The result will be 1.043 lbs. of feed-water, presuming the heating to be done by injection, or under precisely similar conditions in a surface-heater.

Water raised 71.5° from 114.2° to 185.7° will condense per lb.

$$\frac{71.5}{1139-185.7}=0.075 \text{ lbs.}$$

The pound of water originally at 68° will be thus changed into $1.043\times 1.075=1.125$ lbs. of water at 185.7° which, to be raised to 262.3° will condense per lb.

$$\frac{76.6}{1162-262.3}=0.085 \text{ lbs.}$$

The original pound of water will therefore have become

$$1.125\times 1.085=1.220 \text{ lbs.}$$

Similarly, after heating has been done by steam from the first receiver, the weight of the heated water will have become $1.220\times 1.089=1.328$ lbs.

The water having been thus raised to 337.9° Fahr. will only have to take up

$$1208-337.9=870.1 \text{ B.T.U.}$$

in the boiler, the resultant saving having been

$$\frac{1140-870.1}{1140}=0.24.$$

With respect to this saving of 24 per cent. in the heat to be given to the water, the consequent loss of work per pound of steam remains to be calculated. Presuming that the work is equally divided between the four cylinders, which is sufficiently accurate for all practical purposes, the calculation is easy.

SURPRISE.

Normand's Feed-water Heater.

Section on *c d* fig. 291A.

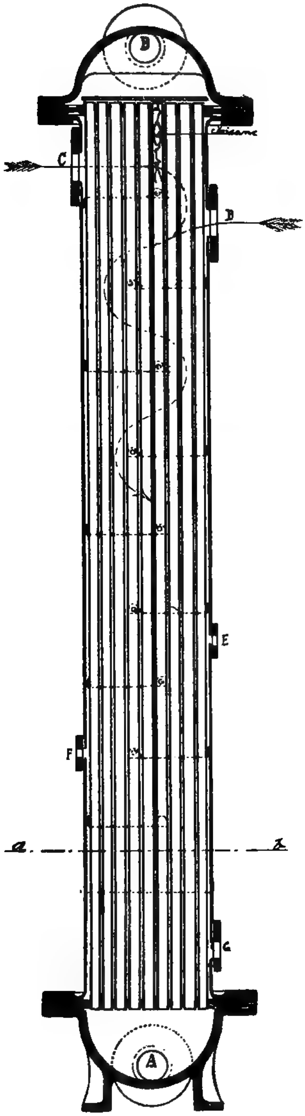


Fig. 291.

A. Feed inlet.
B. Feed outlet.
C. Steam from L.P. casing.
D. Auxiliary exhaust inlet.
E. Equilibrium valve to trap.
F. Air cock.
G. Condensed steam outlet to main condenser.

Wainwright Heater.

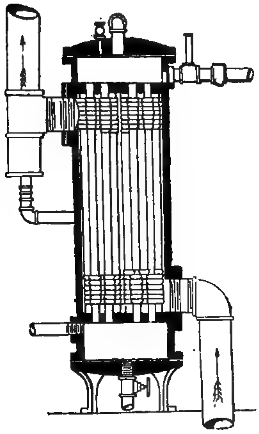


Fig. 292.

Weir's Injection Heater.

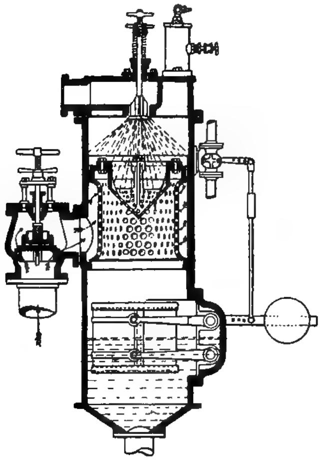
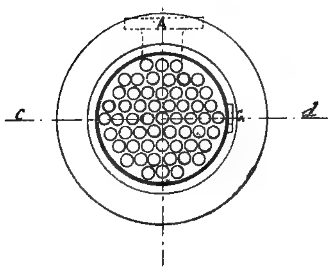


Fig. 293.



Section on *a b* fig. 291.

Fig. 291A.

The 1.328 lbs. of steam produced is employed in doing work and in heating feed-water:—

(1) $1.328-1.220=0.108$ lb. performs one quarter of the total work, and is then condensed;

(2) $1.220-1.125=0.095$ lb. performs half the total work;

(3) $1.125-1.043=0.082$ lb. performs three-quarters of the total work;

(4) 0.043 lb. performs the whole of the normal work;

(5) 1.000 lb. performs the whole of the normal work.

Total 1.328 lbs.

The work that would have been performed by the 1.328 lbs. of steam in the four cylinders is

$$\frac{0.108\times0.75\times0.095\times0.5\times0.082\times0.25}{1.328}=0.11.$$

The final result of the net saving is therefore

$$0.24-0.11=0.13 \text{ or } 13 \text{ per cent.}$$

In practice it has never been proposed to employ four successive heaters. The exhaust steam is not used for fear of air finding its way to the condenser by using a heater which acts practically as a second condenser. Heating is only done once with the steam from one of the receivers.

By a calculation analogous to the above, a theoretical saving of 8 per cent. may be obtained by heating from the third receiver, and of 5 per cent. from the first. In practice it is preferable to use the second receiver; the saving effected depends on the position of the heater, which should preferably be in the engine-room, and close to the point whence it takes its steam. In experiments in 1892 with the Normand feed-heater, an average economy of 21 per cent. was realised when

burning 9.2 lbs. per square foot of grate, and 12 per cent. when burning 13.3 lbs. per square foot of grate.

One of the principal advantages of heating the feed-water is that, on introducing the water hot into the boiler, it is in a position to take up the heat from the heating-surface more readily on coming in contact with it. The circulation is then increased and the transmission of heat by convection improved. This explains the large saving that has been realised when taking steam from the second casing. There is an economy to be obtained when taking live steam direct from the boiler, but it is not so great as in the previous case.

The injection feed-heater, introduced by Messrs Weir in 1871, serves rather to extract the air from the feed-water than to effect a marked saving in coal consumption, at least it was rather with a view to increasing the life of the boiler by extracting the air, that its inventor first introduced it. Fig. 293 shows a Weir's injection feed-heater in section.

The air given off by the feed-water is led away to the condenser through the small pipe shown at the top of the figure. The lower part of the heater forms a reservoir from which the feed-pumps draw, and a float controls by means of a lever, the steam to the pumps, and shuts them off before there is any danger of air being sucked in. As the feed-heater is in communication with the condenser, the temperature therein cannot be high, but the saving effected when using the exhaust from the auxiliary engines is quite appreciable. In some careful tests at sea conducted by Mr Alexander Dalrymple, the consumption without the feed-heater was 1.47 lbs. per I.H.P., and with the heater 1.38 lbs. per I.H.P., that is, a saving of 6 per cent. A similar feed-heater is made in England by the Worthington Pumping Company, and in America by the Blake and Knowles Steam Pump Company.

197. *Apparatus for making good Losses of Fresh Water.—Single Distillers.*—Marine engines cannot be worked without a certain loss of fresh water, either continuous, owing to leakages of all kinds, or occasional, owing to draining into the atmosphere, blowing off, etc. The total quantity of water contained in the boiler and in the feed apparatus would therefore be constantly diminishing were not some

DISTILLER ON BOARD GUNBOAT "CROCODILE."

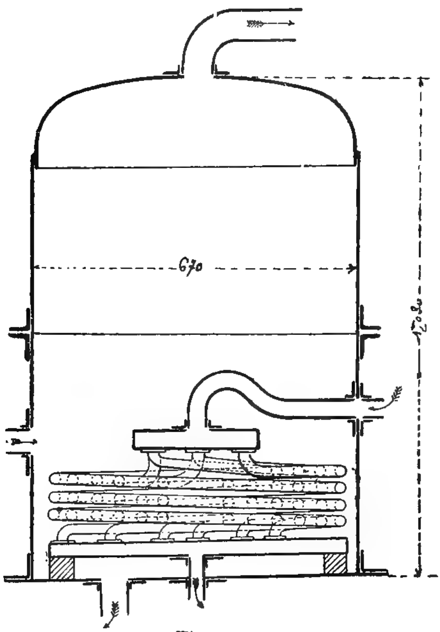


Fig. 294.

supplementary agencies occasionally used for making up this loss.

The use of sea water as "make-up" being nowadays forbidden, it is necessary to have either a reserve quantity of fresh water or an apparatus used for producing fresh water known as a "distiller" or "evaporator."

Distillers have been in use on board ship for many

years. They were formerly solely employed in providing the fresh water required by the crew. These have simply been enlarged so as to cope with the new requirements of the engines and boilers.

For producing drinking water separate condensers are provided; for feed-water, the main condensers of the engines are used.

For a long time steam was produced in boilers fired with coal and fed with sea water, working at a low pressure and constantly blown off. As it was soon found impossible to make room for these auxiliary boilers on small boats, the steam from the main boilers was brought into use for heating purposes. The first distillers were simply cylindrical chests in which sea water was heated by a steam coil. The steam condensed in the coil was returned to the boilers, and the steam, issuing from the distiller, was condensed for drinking purposes. Fig. 294 is an apparatus of this kind, fixed in 1873 on the gunboat *Crocodile*.

It worked very well, but surprise was expressed at the violent ebullition and consequent tendency to prime. This was found to be due to the rapid transmission of heat through a wall, one side of which was in contact with water, and the other with condensed steam.

COUSIN DISTILLER.

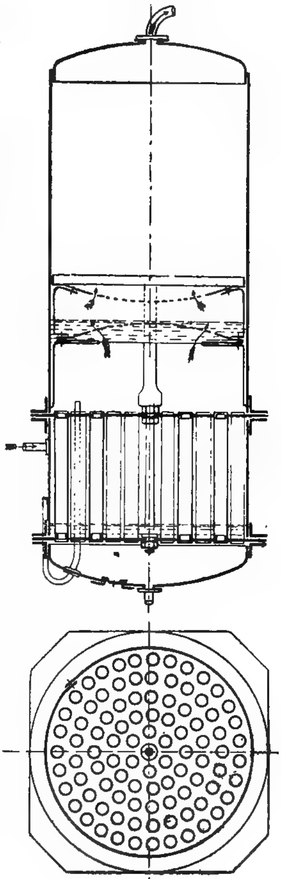


Fig. 295.

The coil was subsequently replaced by a nest of tubes, expanded into two tube-plates and surrounded by steam.

Such are the Cousin condensers, named after the engineer who designed them; they are single acting, and are still in use on many vessels. At the present time coils have been reverted to, as they do not give rise to leaky tube-plates. The Mourraille distiller described in the next paragraph is of this type, and the Weir distiller approaches it very closely. With this type of single distiller, a smaller weight of steam is obtained than in the main boilers from whence the steam for condensation is taken, viz., about 6 lbs. of steam in the evaporators per pound of coal burnt in the boilers. If the production of steam is reduced to 4 lbs. then the total amounts to 12 lbs. in all, supposing the boilers to evaporate 8 lbs. of water per pound of coal burnt.

198. *Multiple Distillers*—In single distillers the heat of the steam produced is entirely lost. In the multiple ones, on the contrary, this steam is utilised, and they are much more economical; they were invented by M. Sochet in 1832.

The principle of these multiple distillers consists in placing several distillers in series, each one serving as a condenser to the preceding one, and as a heater for the succeeding one. Were there no loss of heat from radiation, all the distillers would produce an equal amount of water, and from an originally limited amount of steam an indefinite amount of fresh water could be obtained. There is no paradox in this principle, as there would be no loss of heat, and there is, further, no work to be done.

However, on account of radiation, the production of steam diminishes, from one distiller to the other, at a certain rate q, equal say to 0.7 or 0.8. Consequently 1 lb. of initial steam produces, in successive distillers, q, q^2, q^3 . . . q^n

lbs. of steam ; the quantity of fresh water obtained over and above the first pound condensed is thus expressed:—

$$q + q^2 \ldots + q^n = q\frac{1-q^n}{1-q},$$

of which the limit with n infinite would be

$$\frac{q}{1-q}.$$

M. Sochet's first apparatus consisted of six vessels, one being in reserve, out of each of which the condensed water was extracted by a small hand air-pump. At present three vessels are considered sufficient, and the distiller is therefore a triple one, as shown in Fig. 296.

In this apparatus, as constructed by Messrs Mourraille, the vessel I. takes its steam direct from the main boiler, and heats vessel II., which in its turn heats vessel III. Both the temperature and the pressure naturally diminish from one vessel to the other.

The sea water to be evaporated is first heated in the heater IV. by the water condensed in vessel III. It then passes to distiller III., in which the pressure is sufficiently low to allow of the feed being fed in, merely by the atmospheric pressure and the difference between the sea level and the level of the water in the distiller. Any water that has not been evaporated in distiller III. is passed back by a pump to distiller I. ; what is left after I. passes into II. ; the remainder not evaporated in II. is discharged into the sea.

The water condensed in I. is not fit for anything but the feed make-up ; it is generally run into the condenser, where it makes up for the loss of steam in the distiller.

The steam produced in the three vessels, if required to make good any waste, is also usually sent back to the condenser ; a better plan is to avoid losing the benefit of its heat in this way, and to take it back to the inter-

mediate casing, where it will easily find admittance on

MOURRAILLE'S TRIPLE DISTILLER.

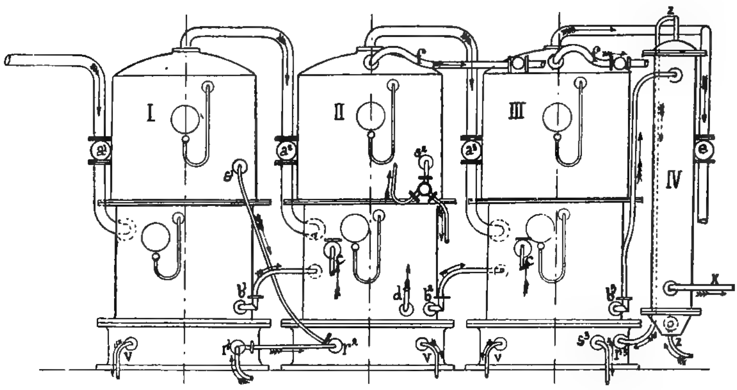


Fig. 296.

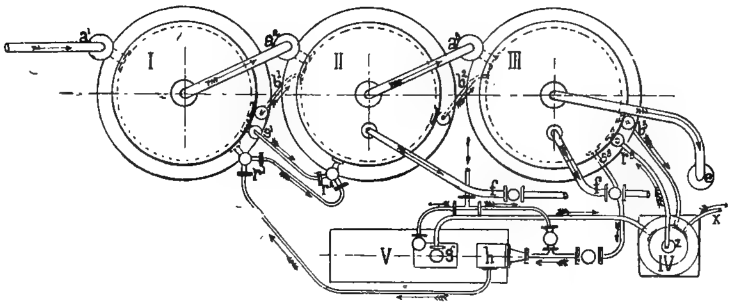


Fig 296A.

I. High pressure distiller.
II. Mean ,, ,,
III. Low ,, ,,

IV. Feed-water heater.
V. Donkey feed.

a^1. Heating steam to distiller I.
a^2. ,, ,, ,, II.
a^3. ,, ,, ,, III.
b^1. Condensed steam outlet of distiller I.
b^2. ,, ,, ,, ,, II.
b^3. ,, ,, ,, ,, III.
c. Auxiliary steam.
d. ,, blow-off.
e. Exhaust to condenser.
f. Steam ,,
g. To cold water pump.

h. To hot-water pump.
r^1. Water inlet to distiller I.
r^2. ,, ,, ,, II.
r^3. ,, ,, ,, III.
s^1. Blow-off of distiller I.
s^2. ,, ,, II.
s^3. ,, ,, III.
v. Drain-cock.
x. Water to hot well.
z. Inlet and outlet of feed-water to heater.

account of its higher pressure. This point will be dealt with in the next section.

The Mourraille distillers are constructed with either tubes or coils. The interior arrangement of coil distillers is given in Fig. 297. This reminds one forcibly of the first distiller constructed by M. Bigot, at Cherbourg. The heating is effected by a coil, through which steam circulates in the centre of the liquid to be vaporised. There are no tube-plate joints. The interior is easily cleaned by taking off the bottom, which is removable.

Single distillers of various sizes and of similar design have been constructed, principally for use on torpedo-boats,

MOURRAILLE COIL DISTILLER.

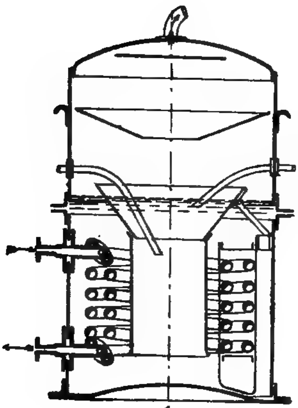


Fig. 297.

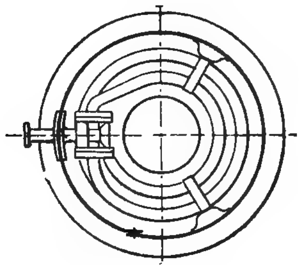


Fig. 297A.

and they work satisfactorily. The only fault to be found with them is their weight, which is excessive. M. Oriolle has, however, constructed some which, while exactly similar in their action, are much lighter.

The production of fresh water, and, in consequence, the economical yield of the triple distillers, is just about three times that of single ones. Experiments made on the *Jean-Bart* and on the *Brennus* have actually resulted in a production of 17 lbs. of fresh water per lb. of coal burnt.

The principal data relative to the Mourraille and to

some other types of distillers, as well as their total yield of fresh water per 24 hours, are given in the following Table:—

—			Total Heating Surface.	Weight of Apparatus Exclusive of Water.	Yield of Water per 24 hours.
			Sq. Ft.	Tons.	Lbs.
Mourraille distillers	Triple tubular distillers . . .	Large size	678·15	5·766	13,228
		Medium ,,	452·10	4·162	8,818
		Small ,,	226·04	2·656	4,409
	Single tubular distillers (Cousin type)	Large size	107·64	1·377	33,069
		Medium ,,	64·58	0·984	19,841
		Small ,,	24·76	0·639	7,716
	Single coil distillers .	Large size	78·04	1·156	24,251
		Medium ,,	43·06	0·875	13,228
		Small ,,	7·00	0·069	2,205
Triple Oriolle distiller			1,324·00	2·789	132,276
Single Weir distillers		Large size	114·10	2·24	55,115
		Medium ,,	78·9	1·31	39,683
		Small ,,	49·94	0·84	24,251

The considerable variations in the heating surfaces, and in the weight, of apparatus similar in principle and of similar yield, tend to show that a standard and definite type is still a long way off.

The rule followed as to the output of the distillers in ships of the French Navy is that 9,000 lbs. a day are to be the output for every 1,000 maximum H.P., with a fresh-water reserve of 4,500 lbs. per 1,000 H.P. This allows, if the engines consume 13 lbs. of steam per horse-power hour, $\frac{1}{36}$th of the steam to be lost without drawing upon the reserve, and to work, when using reserve and all, either for twenty-four hours with $\frac{1}{24}$th of the steam, or for twelve hours with $\frac{1}{18}$th of the steam, and at full speed in every case.

The loss of steam from the main engine, when in charge of a careful engineer, is very slight indeed, in some cases practically nothing at all; but in all auxiliary engines, in consequence of long steam-pipes without steam-traps, the

loss of fresh water is, generally speaking, very considerable.

The loss due to the valves and also the manholes of the boilers may also be of importance.

199. *Distillers, yielding both Fresh Water and Useful Work.—Weir's Distiller.*—The question of distillers is of interest apart from the losses of fresh water in the engines and boilers, however great we may suppose these to be, and also apart from the production of fresh water for the crew. Steam in the form of jets may at times be put to important uses, such as it may not be called upon to perform under ordinary circumstances. The great obstacle in the way of thus employing the steam is the cost of the fuel in making good the loss of fresh water, as has already been shown in Chapter VI. with regard to forced draught, and in Chapter V. in the spraying of petroleum. It has been shown in paragraphs 36 and 61 that, according to the method employed in making use of the steam, the cost of make-up more than doubles the cost of fuel. This estimate is too low in the case of the single distillers, which are those most often met with on modern ships. In reality the cost is multiplied by 1.66, as the fuel consumed evaporates half its own weight of steam.

$$\text{That is } 1 + \frac{1}{1+0.5} = 1.66.$$

In the triple distiller, while the cost of working has to be multiplied by only 1.4, it gives three times the output.

$$\text{That is } 1 + \frac{1}{1+1.5} = 1.4.$$

This cost is still too high, and, further, in order to yield the quantity of fresh water which forced or induced draught may require, the weight of the triple distillers, under existing circumstances, becomes excessive.

It is therefore of vital importance to increase the present output, with the ability to vary it in quantity according to

requirements, while keeping the weight of the apparatus within reasonable limits.

M. Gayde, during a trip with a naval squadron, thoroughly investigated the question of losses of fresh water, and of the means for preventing them. As a result, he advocates an arrangement of distillers which would reduce the cost of production of fresh water.

The principle thus advocated is to employ the steam in a single distiller in such a manner as not to lower its temperature to the point of condensation, and, at the same time, to employ the steam thus produced in doing some useful work in the engine instead of evaporating more fresh water. The original steam, partly lowered in temperature, and the steam raised in the distiller, both having the same, or practically the same pressure, would be returned to one of the receivers of the engine, having a pressure equal to their own. Their evaporative efficiency per square foot of heating-surface depends on the pressure existing in the receiver. Further, the two steams from the distillers can be used in different ways. Theoretically, the total loss of heat might be reduced in this manner to zero, or rather to the simple loss by radiation and conduction of the distiller and piping. The distillers might, indeed, be easily so arranged as to give, if required, a large output at any time when a great quantity of fresh water happened to be required at short notice.

Taking the case of a triple expansion engine with a fall in temperature between the boiler and the condenser of 252° Fahr., it may be divided up thus—

Boiler to first receiver	59.4° Fahr.
First receiver to second receiver	66.6° Fahr.
Second receiver to condenser.	126.0° Fahr.
	252.0° Fahr.

The heating steam can be taken from the boilers, and

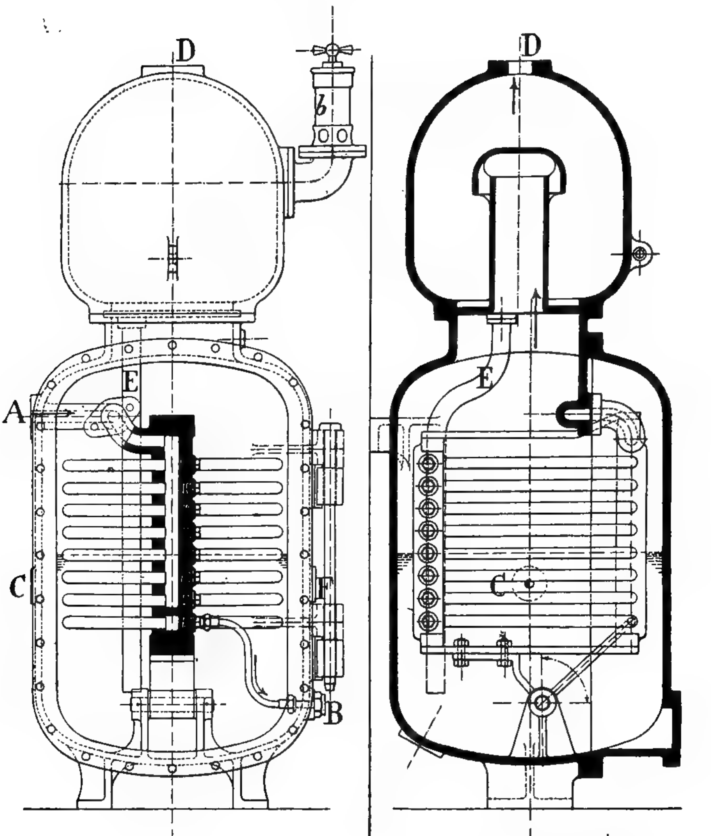
the steam produced carried to the M.P. cylinder, or it can be taken from the first receiver, and the steam produced carried to the L.P. cylinder. The distiller will then work with a difference of temperature between the inside and outside of the tubes of 54° and 72° Fahr. The production will be small but economical. If the steam is taken from the second receiver and the steam produced is led to the condenser, or if it is taken from the boilers and led to the second receiver, there will be a difference of temperature of 126° Fahr., and the distiller will be working under normal conditions while maintaining all the advantages of a double distiller. Lastly, under exceptional circumstances, the total difference of temperature of 252° Fahr. may be used, and a proportionately greater output secured.

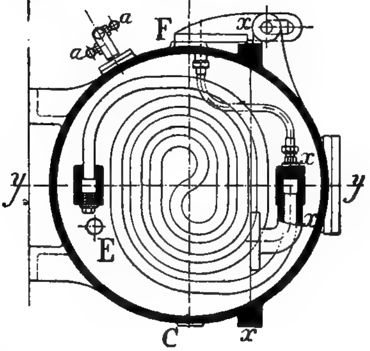
The combination of producing steam doing useful work, is worthy of trial, as the double distillers require very careful handling, and triple distillers are almost impracticable, and need most careful adjustment and manipulation.

Messrs Weir exhibited at the Chicago Exhibition in 1893 an apparatus combining these principles. They used either the steam which had already done a certain amount of work in the main engines, taking it either from the second receiver, or using the exhaust from the auxiliary engines. In this latter case, the distiller really serves as a condenser to the auxiliary engines. It entails increasing the back pressure on the auxiliaries, but utilises the heat of the exhaust steam, which, in the main engines, goes to the main condensers, and a large portion of this heat is necessarily carried overboard by the circulating water.

The low steam pressure used in Weir's distiller necessitates the use of a small condenser with air-pump if fresh drinking water is to be made, but the saving in coal more than compensates for the extra complication. Weir's distiller is shown in Fig. 298 where the nest of straight tubes is replaced by a nest of horizontal curved tubes,

WEIR DISTILLER.





A. Steam inlet.
B. Drain for condensed water.
C. Sea inlet.
D. Steam outlet.
E. Pipe for allowing priming water to return to distiller.
F. Blow-off.
aa. Gauge glass.
b. Saftey-valve.

Fig. 298.

whose ends are connected to two collectors; these tubes may be subject to full boiler pressures.

The casing is fitted with a safety-valve set at about 25 lbs. per square inch. The front of the distiller opens like a door and the nest of tubes swings out, and can be easily cleaned. Practice has indicated the necessity of having a sufficiently large space above the tubes to avoid priming.

An interesting mechanical addition to the Weir distiller consists in the use of two pumps—one feed, and the other brine discharge. These pumps are linked together and work automatically. The capacity of the feed-pump is exactly double that of the brine discharge pump. A proportion of the water from the feed-pump, which can be regulated at will, is sent direct to the discharge pump, thus cooking the brine and making the brine pump more efficient. By the simple adjustment of a pointer, the rate of working can be set to any desired degree of density. The steam to the pumps is regulated by means of a float placed in a vessel attached to the distiller, a loaded valve, placed on the discharge of the feed-pump, serves to control the movement of the float.

CHAPTER XIX.

ACCESSORIES RELATING TO THE DISPOSAL OF ASHES.

200. *The Handling of Coal and Ashes.* — There are as yet no mechanical appliances for handling coal on board worth noticing. A system of coal buckets and mechanical firing was tried some time ago, but it was soon given up and has not again been brought into use. The introduction of briquettes has very much facilitated the handling of fuel, not only in the bunkers, but even in the stokehold. The clearing away of the ashes is, on the other hand, a most important operation for which the old awkward and noisy hand or steam winch is now no longer considered satisfactory.

201. *The De Maupeou Ash-hoist.* — This apparatus was especially designed for use under forced draught with closed stokeholds, where it is difficult to raise the ash-skips, as they have to be passed through air-locks.

The way the difficulty is got over is by grinding the ashes, mixing them with water, and ejecting them into the sea by means of a force pump.

The apparatus has been modified from time to time, and now consists of two jaws, one fixed, the other movable, between which are passed the ashes to be ground (Fig. 299). The fixed jaw, supported on a strong spring, yields slightly should a piece of iron pass through with the ashes. Any

damage from this cause is thus avoided, and the regular working of the apparatus is ensured.

The result of an experiment made at Cherbourg in 1887

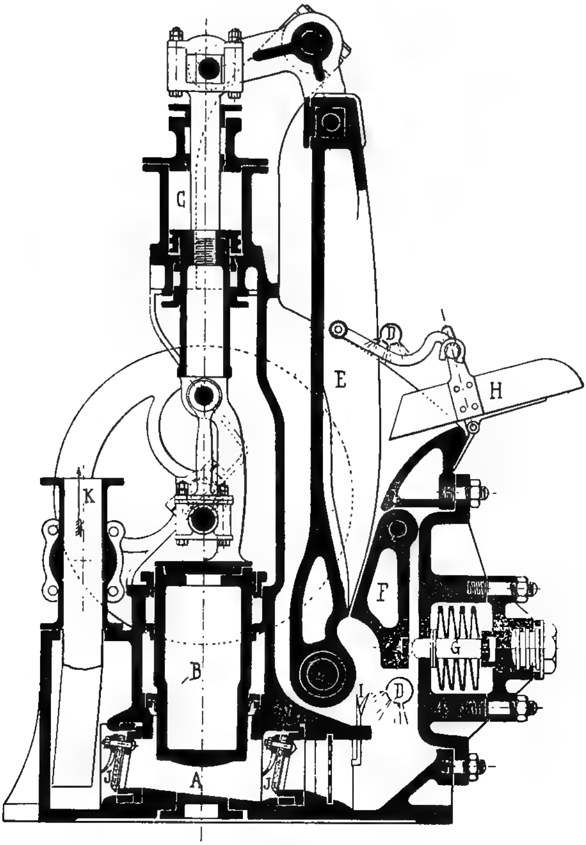


Fig. 299.

A. Body of the pump.
B. Ash-piston.
C. Steam cylinder.
D. Water-pipe.
E. Movable jaw.
F. Fixed jaw, supported by
G. Spring.
H. Rocking-table for receiving ashes.
I. Cock to catch waste.
J. Indiarubber valves.
K. Ashes discharge pipe.

with the De Maupeou ash-hoist, showed that, with a lift of 17 ft., it ejected a weight of $\frac{3}{4}$ lb. of ashes per second. The power absorbed by the grinder and the pump amounted

to 2.170 ft.-lbs. The machine has, as would be expected, an exceedingly small mechanical efficiency, but in these matters steady and easy working is of greater importance than high efficiency.

202. *Water Ash-ejectors.* — Both ashes and clinker may be discharged into the sea, without any grinding, by means of water-ejectors, of which there are several kinds.

In the ejector used on the American ferry-boats, the ashes are first mixed with water in a long vessel into which sea water is admitted through a tap. The ejector-pipe, which withdraws the mixture from the bottom of the vessel, has a jet of water under pressure delivered in the direction of its longitudinal axis by one of the force-pumps on board.

In the See or Trewent ejector (Fig. 300), tried in 1896 at Cherbourg, the dry ashes are tipped directly into the ejector through a hopper. The water jet, with a pressure of from 170 to 260 lbs., is delivered through a tapering nozzle. Small clack valves allow air to enter the ejector-pipe above the nozzle.

SEE ASH-EJECTOR.

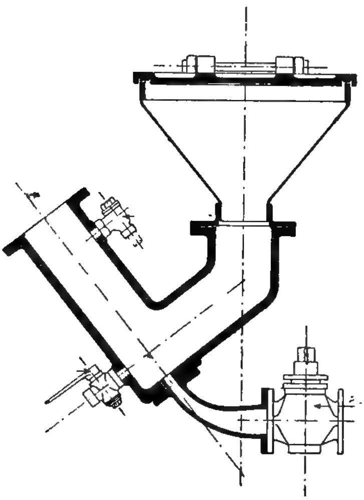


FIG. 300.

With a lift of 18 ft., the apparatus tried delivered 6.4 lbs. of ashes per second, with an expenditure of 3,655 ft.-lbs. on the pump pistons. The mechanical efficiency was therefore equal to 3 per cent. The average discharge for lifts of 18, 22.8 and 27.56 ft., was found to be 9.84, 8.36, and 4.92 tons an hour, the necessary water pressure being 170.8, 206.7 and 241. lbs. per sq. in

respectively. Trifling difficulties occurred which appeared to be easily avoidable.

The See ejector has the further advantage over the grinding ejector, that it is much simpler in construction and in action, besides being four times as effective. Its output is considerable, and allows of very rapid working. It has done good service on the steamers of the Campagnie Transatlantique, and is more suitable for the mercantile marine than for the navy. It would be impracticable to fit a See ejector to every stokehold of a large battleship or cruiser, on account of piercing the side armour, and therefore only two or three are fitted to each ship, whereas there would be no difficulty in so fitting a small ash-pump.

A steam ash-ejector was worked for some time on board the *Corse*; it worked well, but its output was very small. The necessity for economising fresh water acts as a bar at present to the use of steam-ejectors.

APPENDIX I

INTERIM REPORT OF THE COMMITTEE, APPOINTED BY THE LORDS COMMISSIONERS OF THE ADMIRALTY, TO CONSIDER CERTAIN QUESTIONS RESPECTING MODERN TYPES OF BOILERS FOR NAVAL PURPOSES.

Copy of the Letter of Instructions sent to the President.

S. 17864—18248.

Admiralty, S.W.,
6th September 1900.

Sir,—I am commanded by my Lords Commissioners of the Admiralty to inform you that they are pleased to nominate you as Chairman of a Committee which they have decided to appoint for the purpose of considering certain questions arising in connection with the use of various modern types of boilers for naval purposes, as set forth in the terms of reference specified in the succeeding paragraphs of this letter.

(2.) In addition to yourself, the Committee will be composed of the following members:—

Mr J. A. Smith (Inspector of Machinery, R.N.).

Mr John List, R.N.R. (Superintending Engineer, "Castle" Line).

Mr James Bain, R.N.R. (Superintending Engineer "Cunard" Line).

Mr J. T. Milton (Chief Engineer-Surveyor of Lloyd's Register of Shipping).

Professor A. B. W. Kennedy.

Mr J. Inglis, LL.D. (Head of the firm of Messrs. A. & J. Inglis, Engineers and Shipbuilders, Pointhouse, Glasgow).

Commander Montague E. Browning, R.N., and Chief Engineer William H. Wood, R.N., will act as Joint Secretaries to the Committee.

(3.) The points which it is desired that the Committee should investigate and report upon are as follows:—

(*a.*) To ascertain practically and experimentally the relative advantages and disadvantages of the Belleville boiler for naval purposes as compared with the cylindrical boiler.

(*b.*) To investigate the causes of the defects which have occurred in these boilers and in the machinery of ships fitted with them, and to report how far they are preventable either by modifications of details or by difference of treatment, and how far they are inherent in the system. The Committee should also report generally on the suitability of the propelling and auxiliary machinery fitted in recent war vessels, and offer any suggestions for improvement, the effect as regards weight and space of any alterations proposed being stated.

(*c.*) To report on the advantages and disadvantages of the Niclausse and Babcock and Wilcox boilers compared with the Belleville as far as the means at the disposal of the Committee permit, and also to report whether any other description of boiler has sufficient advantages over the Belleville or the other two types above mentioned as a boiler for large cruisers and battleships to make it advisable to fit it in any of Her Majesty's ships for trial.

(4.) For the purpose of making direct experiments between ships fitted with Belleville and cylindrical boilers respectively, the *Hyacinth*, fitted with Belleville boilers, will be placed at the disposal of the Committee as soon as the crew have been sufficiently trained and such trials have been carried out as to ensure that the machinery is in efficient order. A cruiser of similar type fitted with cylindrical boilers will also be placed at the disposal of the Committee when required, for the purposes of comparison.

(5.) For the investigation of defects, copies of the reports of all the defects of machinery and boilers which occurred during the recent naval manœuvres will be placed before the Committtee, and they will be able to inspect ships specially commissioned for the manœuvres, which include the *Ariadne* and *Gladiator* with Belleville boilers and the *Perseus* and *Prometheus* with Thornycroft boilers, with any others that may have returned to any of the home ports.

(6.) The *Europa* is now on passage from Australia, and it is desired that, at a suitable time, an investigation into the causes of her high coal expenditure and machinery defects shall be conducted

under the directions of the Committee, and that she shall afterwards be put through such trials as the Committee think necessary

(7). Information on any special points connected with the behaviour of the boilers or machinery of water-tube boiler ships on ordinary peace service which the Committee may desire to have will be obtained by the Admiralty from any of Her Majesty's ships in commission, and opportunities can be taken when the Channel Squadron is in any of the home ports to examine the boilers and machinery of the *Niobe*, *Diadem*, *Arrogant*, and *Furious*, which have Belleville boilers, and the *Pactolus*, which is fitted with Blechynden boilers.

(8.) The *Pelorus*, fitted with Normand boilers, which has recently returned from three years' continuous service in the Channel Squadron and at the Cape of Good Hope, and the *Powerful*, will also be available for examination during their refits.

(9.) The *Sharpshooter*, fitted with Belleville boilers without economisers, the *Seagull*, fitted with Niclausse, and the *Sheldrake* with Babcock and Wilcox boilers, will be employed in training stokers, and will be available for examination, and, if necessary, for any comparative experiments between these boilers that the Committee may wish to make, though the comparatively low pressure for which the machinery of these vessels was designed makes it impossible to try these boilers under the conditions under which they would work if fitted in a new ship.

(10.) It is particularly desired that any conclusions the Committee may arrive at should be supported by experimental proof as far as possible, and that the Committee should propose any further experiments they think necessary for this purpose.—I am, Sir, your obedient servant,

EVAN MACGREGOR,
Secretary.

Vice-Admiral Sir COMPTON DOMVILE, K.C.B.

COPY OF LETTER ASKING FOR AN INTERIM REPORT

S. 315—407.

ADMIRALTY, S.W.,
4th January 1901.

SIR,—I am commanded by my Lords Commissioners of the Admiralty to inform you that they will be glad to have an interim report from the Boiler Committee, as soon as possible, on any of the points referred to the Committee on which they consider they have collected sufficient evidence or experimental proof to enable them to form a reliable opinion.

The questions to which my Lords especially desire an answer, are the following :—

(1.) With the experience and information which have already been obtained, can it be stated whether water-tube boilers are considered by the Committee to be more suitable than cylindrical boilers for naval purposes?

(2.) Should the answer to the above question be in the affirmative, do the Committee consider that the Belleville boiler has such an advantage over other types of water-tube boilers as to lead them to recommend it as that best adapted to the requirement of H.M. Navy?

(3.) Generally, having regard to the importance of deciding on the types of boilers to be provided for vessels which are ordered in the immediate future, are the Committee prepared at present to make any recommendation, or to offer any suggestions on the extent to which any particular type or types of boilers should be fitted in new vessels?

Whilst their Lordships are anxious to receive an interim report at as early a date as practicable, they in no way wish to press the Committee for a premature expression of opinion.

I may add that any report made should be accompanied by full particulars of all the evidence and experimental data on which the recommendations of the Committee are based.—I am, Sir, your obedient servant,
EVAN MACGREGOR.

The Secretary,
Boiler Committee.

ADMIRALTY,
19th February 1901.

BOILER COMMITTEE.

SIR,—I have now the honour to submit for their Lordships' information the *ad interim* Report called for by their letter S. 315/407 of the 4th January 1901 on the three questions to which the attention of the Committee was especially directed, viz.:—

"(1.) With the experience and information which have already been obtained, can it be stated whether water-tube boilers are considered by the Committee to be more suitable than cylindrical boilers for naval purposes?

"(2.) Should the answer to the above question be in the affirmative, do the Committee consider that the Belleville boiler has such an advantage over other types of water-tube boilers as to lead them to recommend it as that best adapted to the requirement of H.M. Navy?

"(3.) Generally, having regard to the importance of deciding on the types of boilers to be provided for vessels which are ordered in the immediate future, are the Committee prepared at present to make any recommendations or to offer any suggestions on the extent to which any particular type or types of boilers should be fitted in new vessels?"

The replies to these questions are given in the first three paragraphs of the Report, and the reasons for the replies in the remaining paragraphs, with all the advice the Committee are at present able to

give on the subject of the future boiler for the navy, with suggestions for trying two new types of boiler as quickly as possible.

The Report is unanimous with the exception of Mr J. A. Smith, Inspector of Machinery, who, though agreeing with the tenor of the Report as a whole, explains that, in his opinion, the Belleville boiler will give satisfactory results when carefully treated, and considers there is no necessity for delaying the progress of ships already designed for them.

In conclusion, I should like to bring to their Lordships' notice the great zeal and trouble taken by the civilian members of this Committee to attend the meetings and trials necessary to form an opinion on this question, often at great inconvenience to themselves, being all busy men with their own special work to do.—I have the honour to be, Sir, your obedient servant,

COMPTON DOMVILE, Vice-Admiral,
President, Boiler Committee.

The Secretary
of the Admiralty.

AD INTERIM REPORT.

(1.) The Committee are of opinion that the advantages of water-tube boilers for naval purposes are so great, chiefly from the military point of view, that, provided a satisfactory type of water-tube boiler be adopted, it would be more suitable for use in His Majesty's Navy than the cylindrical type of boiler.

(2.) The Committee do not consider that the Belleville boiler has any such advantage over other types of water-tube boilers as to lead them to recommend it as the best adapted to the requirements of His Majesty's Navy.

(3.) The Committee recommend:—

(*a.*) As regards ships which are to be ordered in the future:—That Belleville boilers be not fitted in any case.

(*b.*) As regards ships recently ordered, for which the work done on the boilers is not too far advanced:—That Belleville boilers be not fitted.

(*c.*) As regards ships under construction, for which the work is so far advanced that any alteration of type of boiler would delay the completion of the ships:—That Belleville boilers be retained.

(*d.*) As regards completed ships:—That Belleville boilers be retained as fitted.

(4.) In addition to the Belleville type of boiler, the Committee have had under consideration four types of large straight tube boilers which have been tried in war vessels, and are now being adopted on an extended scale in foreign Navies. These are:—

(*a.*) The Babcock and Wilcox boiler.
(*b.*) The Niclausse boiler.
(*c.*) The Dürr boiler.
(*d.*) The Yarrow large-tube boiler.

(*a*) and (*b*) have also been tried in our own Navy with satisfactory results, and are now being adopted on a limited scale.

If a type of water-tube boiler has to be decided on at once for use in the Navy, the Committee suggest that some or all of these types be taken.

(5.) The Committee recommend that the completion of the two sloops and the second-class cruiser fitting with Babcock and Wilcox boilers, and the sloop and first-class cruiser fitting with Niclausse boilers, be expedited, in order that the value of these types of boilers for naval purposes may be ascertained at the earliest possible date. This is especially important, as the Babcock and Wilcox boiler adopted in the ships under construction differs materially from the Babcock and Wilcox boiler as fitted in the *Sheldrake.*

(6.) The Committee recommend that boilers of the Dürr and of a modified Yarrow type be made and tested at the earliest possible date, under their supervision, with a view of aiding the selection of one or more types of water-tube boilers for use in His Majesty's ships. For this purpose the Committee suggest that two cruisers, not smaller than the "Medea" class, with vertical triple-expansion engines be placed at their disposal, and that they be empowered to order, at once, Dürr and Yarrow boilers to be fitted to them, and to order also the removal of their present boilers and the necessary modifications to their machinery, so that the performance of the types of boilers named may be definitely ascertained under ordinary working conditions from extended seagoing trials. The Committee suggest vessels not smaller than the "Medea" class, because the evidence before them shows that it has been difficult to draw from Torpedo Gunboat trials conclusions fully applicable to larger vessels.

(7.) With reference to paragraph (1), evidence has been given before the Committee to the effect that three most important requirements from the military point of view are:—

(*a.*) Rapidity of raising steam and of increasing the number of boilers at work.

(*b.*) Reduction to a minimum of danger to the ship from damage to boilers from shot or shell.

(*c.*) Possibility of removing damaged boilers and replacing them by new boilers in a very short time and without opening up the decks or removing fixtures of the hull.

These requirements are met by the water-tube boiler in a greater degree than by the cylindrical boiler, and are considered by the Committee of such importance as to outweigh the advantages of the latter type in economy of fuel and cost of up-keep.

(8.) The opinion expressed by the Committee in paragraph (2) has been formed after a personal examination of the boilers in a number of His Majesty's ships, including the *Diadem*, *Niobe*, *Europa*, *Hermes*, *Powerful*, *Furious*, and *Ariadne;* upon the statements of defects which have been placed before them; and the

evidence of the Chief Engineers of those vessels and other officers on the Engineering Staff of the Admiralty and Dockyards. This evidence is being printed, and will be forwarded when ready.

(9.) The Committee consider the following points in relation to the construction and working of the Belleville boiler to constitute practical objections of a serious nature :—

(*a.*) The circulation of water is defective and uncertain, because of the resistance offered by the great length of tube between the feed and steam collectors, the friction of the junction boxes, and the small holes in the nipples between the feed collector and the generator tubes, which also are liable to be obstructed, and may thus become a source of danger.

(*b.*) The necessity of an automatic feeding apparatus of a delicate and complicated kind.

(*c.*) The great excess of the pressure required in the feed pipes and pumps over the boiler pressure.

(*d.*) The considerable necessary excess of boiler pressure over the working pressure at the engines.

(*e.*) The water gauges not indicating with certainty the amount of water in the boiler. This has led to serious accidents.

(*f.*) The quantity of water which the boiler contains at different rates of combustion varying, although the same level may be shown on the water gauges.

(*g.*) The necessity of providing separators with automatic blow-out valves on the main steam pipes to provide for water thrown out of the boilers when speed is suddenly increased.

(*h.*) The constant trouble and loss of water resulting from the nickel sleeve joints connecting the elements to the feed collectors.

(*i.*) The liability of the upper generator tubes to fail by pitting or corrosion, and, in economiser boilers, the still greater liability of the economiser tubes to fail from the same cause :—

Further :—

(*k.*) The upkeep of the Belleville boiler has so far proved to be more costly than that of cylindrical boilers; in the opinion of the Committee this excess is likely to increase materially with the age of the boilers.

(*l.*) The additional evaporating plant required with Belleville boilers, and their greater coal consumption on ordinary service as compared with cylindrical boilers, has hitherto nullified to a great extent the saving of weight effected by their adoption, and, in considering the radius of action, it is doubtful whether any real advantage has been gained. The Committee are not prepared without further experience to say to what extent this may not

(10.) At the time the Belleville boiler was introduced into the Navy in the *Powerful* and *Terrible*, it was the only large tube type of water-tube boiler which had been tried at sea on a considerable scale, under ordinary working conditions. The Committee therefore consider that there was justification for then regarding it as the most suitable type of water-tube boiler for the Navy.

(11.) To obtain satisfactory results in the working of the Belleville boiler, in face of the defects named in paragraph (9), more than ordinary experience and skill are required on the part of the engine-room staff. It appears, however, from the evidence placed before the Committee, that the Engineer officers in charge of Belleville boilers have not been made acquainted with the best method of working the boilers, and that which experience has shown to be most effectual in preventing the pitting and corrosion of tubes.

(12.) In view of the rapid deterioration of economiser tubes in several vessels, the Committee have specially considered whether the extra power per ton of boiler at high rates of combustion, obtained by the use of economisers, has not been too dearly purchased. The evidence before them indicates that at the lower and more usual rates of combustion the *Powerful* type of boiler has given results as satisfactory as the economiser type. It is at the same time less complex, and free from the special risks of tube deterioration which have proved so serious in many cases, notably in the *Europa*. They therefore recommend, for ships under construction, that the non-economiser type should be reverted to where practicable, with the tubes raised higher above the firebars to increase the combustion space, and that where possible the steam collectors should be made larger, and more accessible internally.

(13.) The evidence before the Committee shows that a large proportion of the coal expended in the Navy is used for distilling and other auxiliary purposes, in harbour as well as at sea. For such purposes, the cylindrical boiler is, in the opinion of the Committee, more suitable and economical than any type of water-tube boiler. They recognise that there are objections to fitting cylindrical and water-tube boilers in combination, but they believe that those drawbacks would be more than compensated for by resulting advantages, observing that the cylindrical boilers could be used for supplying distilled water in case of failure or insufficiency of the evaporating plant. On these grounds, it is considered desirable that all the new vessels of large power should be provided with cylindrical boilers to do the auxiliary work.

(14.) The Committee have to state, for the information of their Lordships, that a series of comparative trials for determining economy in coal and water consumption were arranged in October 1900 for His Majesty's ships *Minerva* and *Hyacinth*. The trials of the former ship commenced on January 7th, as soon as she was ready, but were temporarily interrupted by recent events. The Committee are, however, now informed that the *Minerva* will not be again available until after March 2nd, and that the *Hyacinth* will not be ready to

commence her trials until the first week in April. It is proposed to include in these trials a full-speed run for both ships from Portsmouth to Gibraltar and back.

COMPTON DOMVILE, *Vice-Admiral and Chairman.*
JAS. BAIN.
JOHN INGLIS.
ALEX. B. W. KENNEDY.
JOHN LIST.
J. T. MILTON.

M. E. BROWNING, } *Joint Secretaries.*
WM. H. WOOD, }

I concur with the above Report, except as regards paragraph (3), and on the point dealt with in that paragraph my report is as follows :—

(1.) Although the Belleville boiler has certain undesirable features, I am satisfied, from considerable personal experience, and from the evidence of Engineer officers who have had charge of boilers of this type in commissioned ships, that it is a good steam generator, which will give satisfactory results when it is kept in good order and worked with the required care and skill.

I am also satisfied, from my inspection of the boilers of the Messageries Maritimes Company's S.S. *Laos*, after the vessel had been employed on regular mail service between Marseilles and Yokohama for more than three years without having been once laid up for repairs, that, with proper precaution, the excessive corrosive decay of the tubes which has occurred in some instances can be effectually guarded against.

(2.) Having in view the extent to which Belleville boilers have already been adopted for His Majesty's ships, and the fact that there are now three or four other types of water-tube boilers which promise at least equally good results, I am of opinion that, pending the issue of the final report of the Committee, Belleville boilers should not be included in future designs. At the same time, I see no necessity for delaying the progress of ships which have been designed for Belleville boilers in order to substitute another type of boiler. JOS. A. SMITH.

APPENDIX II

THE COMMITTEE ON NAVAL BOILERS.

H.M.S. *Bulwark*, AT RAPALLO,
12th June 1904.

SIR,—I have the honour to submit, herewith, to be laid before the Lords Commissioners of the Admiralty, the final Report of the Boiler Committee of which I am President. Although I have not been present at the experiments carried out during the last two years, I have received from time to time all the reports, and they show the great care and pains taken by the Committee to obtain correct results.

2. With reference to our previous Report, I am compelled to say that my experience with the Belleville boilers on the Mediterranean Station has been very favourable to them as a steam generator, and it is clear to me that the earlier boilers of this description were badly constructed and badly used. We have had no serious boiler defects in any of the ships out here, and the fact that two ships are about to be recommissioned with only the ordinary annual repairs being undertaken shows that their life is not so short as I orginally supposed. However, the second commission of these ships will be a very good test of the staying capabilities of their boilers.

3. In conclusion, I cannot express too highly my opinion of the work done by my colleagues on the Committee.—I have the honour to be,

SIR,
Your obedient servant,
(*Signed*) COMPTON DOMVILE,
Admiral and Commander-in-Chief,
President of the Boiler Committee.

The Secretary to the Admiralty.

REPORT OF THE COMMITTEE ON NAVAL BOILERS.

June 1904.

1. The Committee on Naval Boilers appointed by the Lords Commissioners of the Admiralty in September 1900, having completed their investigations and experimental trials, and being in a position to recommend standard types of boiler for use in H.M. Navy as requested in their Lordships' letter of 28th February 1901, have the honour to submit their final Report.

2. A statement of the work of the Committee up to May 1902 was given in paragraph 2 of their Report of that date. Since then the reboilering of H.M.S. *Medea* with Yarrow large-tube boilers and of H.M.S. *Medusa* with Dürr boilers, together with the necessary machinery alterations, have been completed under the supervision of the Committee, and the boilers of both ships have been thoroughly tested. The results obtained are recorded in a separate Report. As requested by their Lordships in their letter $S\frac{16683}{28331}$ of 19th November 1902, the Committee have also carried out a series of trials of the Babcock & Wilcox boilers of H.M.S. *Hermes*, which extended from 7th October 1903 to 16th May 1904. These trials also form the subject of a separate Report.

3. The Committee have from time to time reported the results of their investigations, and they have also answered such questions as have been put to them by their Lordships. The Reports and other documents which have already been forwarded include :—

(*a*) The Interim Report forwarded on the 19th February 1901.

(*b*) Minutes of the evidence given before the Committee,

together with the Appendix thereto, forwarded 26th April 1901.

(*c*) Report on the trials of the *Hyacinth*, *Minerva*, and *Saxonia*, together with a Summary of Conclusions, forwarded 27th November 1901.

(*d*) Progress Report for the year 1901, forwarded 31st December 1901.

(*e*) Report on the relative economy and efficiency of Belleville and cylindrical boilers in commissioned ships, forwarded 29th April 1902.

(*f*) Report of May 1902, together with the Appendix thereto.

(*g*) Report on the trials of the *Seagull*, *Sheldrake*, *Espiègle*, and *Fantôme*, forwarded 5th August 1902.

There are now submitted with this Report :—

(*h*) Report on the trials of the *Medea* and *Medusa*.

(*i*) Report on the trials of the *Hermes*.

4. The Report of May 1902 was intended to be final as regards the Belleville boiler, and the Committee have since seen no reason to modify the opinion expressed in paragraph 6 of that Report, viz., that it is "undesirable to fit any more of this type in H.M. Navy."

5. In paragraph 5 of their Report of May 1902, the Committee stated that the experience obtained by them since the date of their Report of February 1901, had confirmed them in the opinion that "the advantages of water-tube boilers for naval purposes are so great, chiefly from a military point of view, that, provided a satisfactory type of water-tube boiler be adopted, it would be more suitable for use in H.M. Navy than the cylindrical type of boiler."

In their Reports of 1901 and 1902, the Committee expressed the opinion that four different types of water-tube boiler, viz :

(*a*) Babcock & Wilcox,
(*b*) Niclausse,
(*c*) Dürr, and
(*d*) Yarrow, large-tube,

were sufficiently promising to justify their use in H.M. Navy in combination with cylindrical boilers. Having concluded their experimental investigations, they are now satisfied that

two of these four types, viz., the Babcock & Wilcox, similar to that tried in the *Hermes*, and the Yarrow large-tube, similar to that tried in *Medea*, are satisfactory, and are suitable for use in battleships and cruisers without cylindrical boilers. In the Babcock & Wilcox boiler, the generating tubes are nearly horizontal; in the Yarrow boiler, they are nearly vertical. Each type has its particular advantages, and only long experience on general service can show which is, on whole, the better boiler. For the present, the Committee unanimously recommend both types as suitable for Naval requirements.

In making these recommendations, the Committee recognise that the upkeep of any water-tube boiler is likely to be heavier than that of the cylindrical boiler, but they are of opinion that the two types they now recommend will cost less for upkeep than the other types of large straight-tube boiler which they have had under trial.

6. The Committee make these recommendations after investigations and trials carried out under their superintendence extending over a period of nearly four years.

The ships in which each type of boiler has been tried by the Committee are :—

Cylindrical . .	H.M.S. *Minerva* and R.M.S. *Saxonia*.
Belleville . .	H.M.S. *Diadem* and H.M.S. *Hyacinth*.
Babcock & Wilcox . . .	H.M.S. *Sheldrake*, H.M.S. *Espiégle*, and H.M.S. *Hermes*.
Niclausse . .	H.M.S. *Seagull* and H.M.S. *Fantôme*.
Dürr . . .	H.M.S. *Medusa*.
Yarrow large-tube	H.M.S. *Medea*.

7. Although the Committee have no knowledge of any type of water-tube boiler which is likely to prove more suitable for H.M. ships than the two recommended, there are other types which may be considered worthy of trial later on. If any type of boiler is considered in future to be of sufficient merit to justify its trials in the Navy, it is recommended that it be fitted in a new vessel not smaller than a second-class cruiser.

8. As in their previous Reports, the Committee do not offer any remarks on the most suitable type of boiler for small vessels of high speed. From the nature of the case,

some form of "express" boiler with small tubes closely pitched is absolutely necessary in order to obtain such a ratio of output to weight of boiler as is required in torpedo-boats and destroyers. For small cruisers, however, which have to keep the sea and act with the Fleet, it is probable that a boiler such as the Yarrow large-tube would, on the whole, give better results than the "express" types which have hitherto been fitted.

9. In reference to paragraph 3 (*b*) of their Lordships' letter of 6th September 1900, and to the Committee's Report of May 1902, they desire to call attention to the break-down of the *Hyacinth* machinery on 16th February 1903, and to the trouble experienced with the bearings in the *Hermes* during the homeward run from Gibraltar, which strengthen the recommendation of the Committee contained in paragraph 13 (*a*) of the Report of May 1902, viz., "They consider it desirable, where practicable, to increase the length of stroke and reduce the number of revolutions per minute as compared with the recent practice in H.M. Service."

10. The principal comparative results on which the recommendations of the Committee are based are set forth in the succeeding paragraphs. Full details are given in the separate Reports of Trial.

11. *Thermal Efficiency of Boilers.*—The full tables which are appended to the Committee's Reports give the efficiency of each type of boiler under very varied conditions. The results are here summarised :—

The best obtained with the Babcock & Wilcox boilers of the *Hermes* were during the trials of furnace gas baffling, the boilers in the middle boiler-room, with vertical baffles and a forced air supply over the fires, giving the high efficiency of 81 per cent. on a 30 hours' trial when 20 lbs. of coal were being burnt per square foot of fire-grate per hour, and an efficiency of 77.8 per cent. on a 29 hours' trial when burning 27 lbs. per square foot, these rates of combustion corresponding to the ordinary rate of steaming and to the full power of the boilers respectively. The boilers of the *Hermes* with the restricted up-take baffling and without any special air supply over the fires, had a maximum efficiency of 75.8 per cent. on a 12 hours' trial when burning 20.5 lbs. per square foot per hour. On three

trials of over 24 hours' duration each, and when 19 lbs. were being burnt per square foot per hour, the efficiency was in each case practically 71 per cent. When burning 29 lbs. per square foot per hour for 7 hours, the efficiency of these boilers were 66.3 per cent.; but the weather during this test was so bad that the trial, which was to have been of 8 hours' duration, had to be stopped after the seventh hour on this account. During the baffling trials, however, in good weather, an efficiency of 70.3 per cent. was obtained on the 30 hours' trial, when burning 27 lbs. per square foot per hour, or practically the full output.

The maximum efficiency of the Yarrow boilers of the *Medea*, viz., 75.7 per cent., was obtained on a 26 hours' trial when burning 18 lbs. per square foot per hour; their efficiency, when burning at the maximum rate of combustion, viz., 40 lbs. per square foot per hour for 8 hours, was 69.5 per cent. On trials of over 24 hours' duration each, burning from 17 to 21 lbs. per square foot per hour, the efficiency remained at or over 75 per cent.

The Belleville boilers of the *Hyacinth* had a maximum efficiency of 77.2 per cent. recorded on a 24½ hours' trial, when 16 lbs. of coal were being burnt per square foot of fire-grate per hour. When burning 20 lbs. per square foot per hour for 11 hours, the efficiency was 73.3 per cent., and burning 17.4 lbs. for 24 hours, it was 71.8 per cent. The efficiency of these boilers on an 8 hours' trial in fine weather, when burning 27 lbs. per square foot per hour, corresponding to the full output of the boiler, was 65 per cent.

The maximum efficiency of the Dürr boilers of the *Medusa* was 64.8 per cent., obtained on an 8 hours' trial, when burning 35 lbs. per square foot per hour, this being the maximum rate of combustion with these boilers; the efficiency, when burning 16 lbs. per square foot per hour for 26 hours, was 63.8 per cent. On trials of over 24 hours' duration each, and burning 18 lbs. and 21 lbs. per square foot, the efficiencies were 61.7 per cent. and 60.3 per cent. respectively.

Of the cylindrical boilers tried, those of the *Saxonia*, on the only trial made, which was of 13 hours' duration, and on which 20 lbs. per square foot per hour was burnt, had the high efficiency of 82.3 per cent.

The maximum efficiency obtained with the cylindrical boilers of the *Minerva* was 69.7 per cent., which was recorded on a 25 hours' trial when burning 14 lbs. per square

foot per hour; on a trial of $8\frac{1}{2}$ hours' duration, with retarders in the plain tubes and burning 29 lbs. per square foot, the efficiency was 68.4 per cent.

In the smaller ships, the maximum efficiency of the Babcock & Wilcox boilers tried was 66 per cent. on a 12 hours' trial burning 18 lbs. per square foot per hour in the *Sheldrake*, and 73.2 per cent. on a 9 hours' trial burning 13 lbs. per square foot in the *Espiégle*. The maximum efficiency obtained by the Niclausse boilers of the *Seagull* was 66.9 per cent. on an 8 hours' trial burning 13 lbs. per square foot, and by those of the *Fantôme*, 69.8 per cent. on a 9 hours' trial burning 14 lbs. per square foot.

12. A noticeable feature in connection with the boiler efficiencies is the improvement in the results obtained with the later boilers of the Babcock & Wilcox type. The earliest of these, fitted in the *Sheldrake* in 1898, showed efficiencies ranging from 66·0 per cent. to 59·2 per cent.; the boilers fitted in the *Espiégle* in 1901 showed improved efficiencies ranging from 73.2 per cent. to 63.1 per cent. Those of the *Hermes* fitted in 1903, show a still further gain in economy, the efficiencies ranging from 75.8 per cent. to 66.3 per cent., and the same boilers, after modification, showed, on one occasion, the high efficiency of 81 per cent. It is noticed in this connection that the three sets of Babcock and Wilcox boilers tried differ from each other in the arrangement of their heating surface and furnace gas baffling. The boilers of the *Sheldrake* were fitted throughout with tubes $1\frac{13}{16}$ ins. in diameter, without any baffles for furnace gases; the boilers of the *Espiégle* were fitted throughout with tubes $3\frac{15}{16}$ ins. in diameter, vertical baffles being placed among the tubes and causing a zigzag flow of the gases; the boilers of the *Hermes* were fitted with two rows of $3\frac{3}{8}$ ins. diameter tubes immediately over the fire, the remainder of the tubes being $1\frac{13}{16}$ ins. diameter and the baffling of the furnace gases was effected by a restriction of the space for the passage of the gases between the top row of tubes. Those boilers of the *Hermes* which showed the efficiency of 81 per cent. were similar in construction to those last mentioned, but the baffling of the furnace gases was by a vertical system which caused a zigzag flow of the gases over the heating surface, and, in addition, a forced air supply was introduced above the fires. (See "Report on the Trials of H.M.S. *Hermes*.")

The arrangement of the heating surface in both the earlier and later boilers of the Niclausse type was the same, and the thermal efficiencies of the two sets of boilers were very similar.

13. *Wetness of Steam.*—As explained in other Reports, the wetness of the steam was taken throughout the Committee's trials by means of a Carpenter's calorimeter. Experience in the *Medusa* satisfied the Committee that the results registered by this instrument are trustworthy.

As regards the production of *dry* steam at all rates of combustion, the Yarrow large-tube and the later Babcock and Wilcox boilers have given the best result.

14. *Loss of Water.*—The loss of feed-water with each of the four types of boiler under consideration has been moderate throughout the Committee's trials. In the runs to Gibraltar and back, carried out with the *Medea* and *Medusa* the loss of water was small, being at the rate of 1.6 and 1.8 tons per 1,000 horse-power per day respectively. On the 140 hours' endurance trial of the *Hermes* the loss was 3.8 tons per 1,000 horse-power per day.

The loss of water may be expected to be greater in boilers fitted with many doors than in those fitted with but few and to increase as the doors and joints become worn. In this respect, the Yarrow boiler, having only three manhole doors, has an advantage.

15. *Examination and Cleaning of Interiors of Tubes.*—Of the boilers tried by the Committee, the Yarrow boiler can be internally examined and cleaned in the shortest time and with the least amount of labour—to obtain access for such an examination and cleaning it is only necessary to remove three manhole doors. The Babcock and Wilcox type is less easily examined and cleaned—two small doors have to be removed for each tube, and these have to be rejointed after the examination and cleaning have been completed. In order to carry out a thorough examination of the tubes of the Dürr boiler, it is necessary to remove a hand-hole door at the front of each tube, the diaphragm washer of the internal tube, the internal tube itself, and the cap nut at the back end of the generating tube; but, in order to carry out a thorough cleaning, it is also necessary to remove the generator tubes from the boiler, and after the cleaning is

complete, these have to be replaced, this being a long and tedious process. The work connected with the examination and cleaning of the tubes of Niclausse boilers is very similar to that necessary with the Dürr boiler. Further, the cap nut at the back end of the Dürr boiler tube permits of each tube being readily emptied, while owing to the back end of Niclausse boilers being inaccessible, some process is necessary to empty the tubes when required, such as blowing the water out of the tube by a special pump and hose.

The necessity for being able to withdraw each of the tubes in a direct line with its axis, renders the clear space required for the installation of Dürr and Niclausse boilers considerably more than would be required for boilers of other types. For warships, where the stokehold space is very limited, this must necessarily cause considerable inconvenience in the arrangement of pipes and auxiliary machinery.

16. *External Cleaning of Tubes.* — In both the *Medea* and the *Hermes* it is possible to partially clean the tubes externally, when the fires are alight, by means of air lances.

The tubes in the *Medea* can be thoroughly cleaned externally when the fires are not alight, as they can be swept in three directions, viz., from the furnace, from the smoke-box and from the front of the boiler. The tubes of the Dürr and Niclausse boilers cannot be so thoroughly cleaned externally in place as those of the *Medea*, the number of rows being greater and the overlapping of the baffles preventing portions of certain tubes being touched. In the Babcock & Wilcox boilers, the tubes can be swept horizontally through side doors fitted to the casings, but, as the boilers in the *Hermes* were originally fitted, the sweeping in a vertical direction was difficult. After the alterations of baffling, the sweeping vertically can be carried out, but necessitates the removal of portions of the baffles. It is to be recognised that any system of baffling among the tubes, however it may improve the circulation of the gases, renders the cleaning of the tubes themselves more difficult.

17. *Bending of Tubes.*—After the *Medusa* had completed her preliminary runs, it was found that all the tubes of the bottom rows had curved upwards in the middle, the maximum bending being $1\frac{1}{16}$ ins., and these tubes were

removed and straightened before starting on the Committee's trials. These tubes had to be straightened again in August 1903, and again at the conclusion of the Committee's trials in February 1904. When the Committee visited H.M.S. *Berwick* in April 1904, it was noticed that the tubes of the bottom rows of the boilers (Niclausse type) were bent upwards, and the members were informed that the maximum bending on the 22nd March 1904 was $\frac{5}{8}$ in.; the ship was new in 1903, and only commissioned in December of that year. With the Niclausse, and also with the Dürr, boiler, considerable bending of the tubes of the bottom rows must be expected, and it will be necessary to straighten these tubes when the amount of bending exceeds $\frac{3}{4}$ in. This will entail a considerable amount of extra work with these types of boiler, which will be off service for corresponding periods. The upward bend of the generator tube is often greater than the space between the inner and outer tubes, and as the inner tube, which is only supported at the two ends, remains straight, it is liable to touch the outer tube at some point, thus impeding the circulation of water between them. To prevent this, it may be necessary to support the inner tube at the middle of its length as well as at the back end, so that it must bend with the outer tube.

In the case of the Yarrow boilers of the *Medea* the Committee experimented in six of the boilers with the fire-rows of tubes purposely bent, as described on page 9 of the "Report on the trials of the *Medea* and *Medusa*," with the object of overcoming some slight leakages of tube ends which showed themselves when working under forced draught. In two boilers, the tubes of the fire-rows were left straight. Although these bent slightly in use, no trouble was experienced with them; and, during the later trials, these boilers proved to be as satisfactory as regards freedom from leakage as those in which the fire-rows had been put in bent. The Committee have suggested in their letter of the 21st December 1903, concerning the Yarrow boilers proposed for H.M.S. *Warrior*, that the tubes of the fire-rows be bent 1 in. from the straight, and this recommendation they think should apply to future designs.

In the Babcock & Wilcox boilers of the *Hermes*, although some of the tubes of the bottom rows have bent, no leakage of tube ends has resulted, and it has not been necessary to remove any tubes for straightening or renewal.

18. *Corrosion of Tubes and Wear of Casing and Uptakes.*—In none of the four types of water-tube boiler which were recommended for trial by the Committee has there been any considerable corrosive decay of tubes, and the ordinary wear has been very slight. On the conclusion of the Committee's trials, the tubes of the boilers of the *Medea* and *Hermes* had not deteriorated to any appreciable extent. This applies also to the *Medusa*, except that the internal tubes have shown signs of roughening.

In the *Medusa* (Dürr boiler), there was some buckling of the side casings of the boilers and some of the casing doors at the back of the boilers became warped and burnt.

No trouble was experienced in connection with the casings and uptakes of the Yarrow boilers of the *Medea* and very little with those of the Babcock & Wilcox boilers of the *Hermes*. From the experience of the Committee with the boilers of the S.S. *Martello*, employed on the Atlantic trade for nearly four years, and also from their experience to date with the *Hermes*, it is considered that the durability of the casings and uptakes of Babcock and Wilcox boilers will prove to be satisfactory under the ordinary conditions of naval service.

In the Yarrow boiler the temperature of the furnace gases is considerably reduced before they reach any part of the side casings, and, in consequence of this moderate temperature, the casings and uptakes of the *Medea's* boilers were uninjured on the conclusion of the Committee's trials.

In this respect the Yarrow boiler is superior to the other types of water-tube boiler which have been tried by the Committee.

19. *Liability to Damage from being forced.*—The makers of the Dürr boilers stated that not more than 35 lbs. of coal should be burnt per square foot of fire-grate per hour in the *Medusa*. The Committee consider that this limitation of the quantity of coal to be burnt was prudent, as the overheating and bending of tubes in one of the boilers during the full-power homeward run from Gibraltar were, in the opinion of the Committee, due to the fact that the safe limit had been exceeded. It is also considered that the limitation of the amount of coal to be burnt per square foot of grate applies with even greater force to the Niclausse boiler, as

the supply of water to the tubes is freer in the case of the Dürr boiler than in that of Niclausse. As the result of their trials, the Committee find that the Yarrow boiler can be severely forced without danger, and that the Babcock and Wilcox boiler can with safety be forced to the extent shown in the Reports.

20. *Skilled Firing required.*—The satisfactory stoking of water-tube boilers requires a higher degree of skill than that of cylindrical boilers, and this is more necessary with the large grates of the Dürr, Niclausse and Babcock and Wilcox boilers than with the smaller grates and better shape of combustion-chamber of the Yarrow. The stoking in the *Medea*, *Medusa*, and *Hermes* was good throughout the trials, and towards the end was excellent. Under ordinary service conditions, such good firing can hardly be expected, at least until a vessel has been some time in commission. Good results can, however, be obtained with Yarrow boilers with engine-room complements new to the ship, as shown by the trials to Malta and back which have been made by the *Medea* since the completion of the Committee's trials with that vessel.

21. *Superheated Steam.*—The Dürr boiler was the only one tried by the Committee which had any arrangements for superheating. It was fitted with complicated directing plates in the steam collector and with superheater tubes. The fittings in the steam collector are undesirable, and they and the superheater tubes will probaby require frequent renewal, while the amount of superheat obtained by their use was small, even when the temperature of the funnel gases was abnormally great. The results obtained were not sufficient to enable the Committee to express any opinion as to the value of superheating as applied to naval boilers.

22. *Feeding of the Boilers.*—No trouble has been experienced with the feeding of any of the four types of boilers under consideration. In the *Medea* and *Medusa*, the boilers were fitted with automatic feed-regulators. It was found, however, that these were not sufficiently sensitive in opening and closing (allowing a variation of level of about 6 ins. in the gauge-glass); the feed was therefore regulated throughout the trials by hand, no trouble being experienced in doing this. For a similar reason, the feed was regu-

lated by hand in the *Hermes* during the trials. In the *Medea* the feed-regulators were inside the steam collectors and interferred with the examination and cleaning of the middle rows of tubes. The Committee consider that the balance of advantages rests with the omission of automatic feed-regulators in boilers such as the Yarrow large-tube and the Babcock & Wilcox, where there is a fairly large reserve of water in the boiler.

23. *Salt Water.*—The Report on the trials of the *Medea* and *Medusa* contains a description of experiments made on the Yarrow and Dürr boilers in regard to their behaviour when working with brackish water. These experiments, so far as they went, indicated that neither type of boiler was likely to give trouble from this cause. In the case of the Yarrow boiler, this result has been corroborated by the fact that on a recent voyage the *Medea* is reported to have had leaky condenser tubes and a corresponding density in the boilers without any bad effect.

24. *Relative Weights.*—In the case of the *Hermes*, the *Medea* and the *Medusa*, the new boilers were installed without any alterations being made in the stokehold floor spaces. A comparison of weight and maximum output of the boilers gives the following results:—

Type of Boiler.	Ship.	Weight of boiler room installation.	Maximum output of steam per hour.	Output of steam per hour per ton of boiler room weights.	
		Tons.	Lbs.	Lbs.	
Cylindrical . .	*Saxonia*	1,000 abt.	132,600	132·6	
,, . .	*Minerva*	567	167,100	295	With retarders.
,, . .	,,	558	156,200	280	As originally fitted.
Belleville . .	*Hyacinth*	454	178,700	394	
Yarrow .	*Medea*	330	157,800	478	
Dürr . .	*Medusa*	314	158,000	503	
Babcock & Wilcox	*Hermes*	490	200,000	410	With vertical baffles, and forced air supply above the fires.
,, ,, .	,,	481	182,300	380	As originally fitted.
,, ,,	*Sheldrake*	125	43,840	351	
,, ,, .	*Espiègle*	95	24,780	261	
Niclausse . .	*Seagull*	135	48,450	359	
,, . .	*Fantôme*	26·5	22,780	297	

25. The Committee are under great obligation to Mr C. J. Wilson, F.C.S., who has, during the four years of their work, given his valuable personal attention to the analysis of funnel gases and of coal samples without any remuneration. They are also much indebted to Messrs Thomas Wilson, Sons & Company, for permission to examine the boilers of the S.S. *Martello*, and to Mr W. S. Hide, the Superintending Engineer of that Company, for affording the Committee facilities for carrying out the inspections and giving information concerning the results obtained in the running of that vessel.

26. The Committee desire in conclusion, to place on record their appreciation of the assistance which they have received from their Secretaries. Captain Browning, R.N., acted as Joint Secretary until his appointment to H.M.S. *Ariadne* in 1902. Engineer-lieutenant W. H. Wood, R.N., has continued to act as Secretary throughout their whole work. The diligence and energy which the latter officer has shown in carrying out his work, his knowledge of the scientific as well as of the practical side of marine engineering, and his capacity for dealing both with details and with general organisation, have been invaluable to the Committee throughout, and especially in connection with the carrying out of their boiler trials at sea, a work of no little difficulty and complexity, and they desire to bring his services to the favourable notice of their Lordships.

(*Signed*) COMPTON DONVILE.
Admiral and Chairman.
JAS. BAIN.
JOHN INGLIS.
ALEX. B. W. KENNEDY.
JOHN LIST.
J. T. MILTON.
JOS. A. SMITH.

WM. H. WOOD,
Secretary.

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